FINAL REPORT

on

METAL-DETERGENT/CLEANER COMPATIBILITY

Contract No. F04606-89-D-0034-Q805

to

AEROSPACE GUIDANCE AND METROLOGY CENTER
NEWARK AIR FORCE BASE

January 14, 1994

by

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Executive Summary

The Aerospace Guidance and Metrology Center (AGMC), located at the Newark Air Force Base (NAFB) in Newark, Ohio, repairs and services inertial navigation and guidance equipment for the United States Air Force and other Department of Defense (DoD) agencies. Until recently, AGMC has used large quantities of environmentally unfriendly, ozone-depleting chemicals (ODCs) such as CFC-113 or 1,1,1 Trichloroethane (TCA) in their cleaning and degreasing procedures. During the last few years, AGMC has been evaluating alternative, environmentally acceptable chemicals to replace their ODC cleaners.

This report describes the results of a study to determine the feasibility of using aqueous cleaners to replace the ODCs without causing unacceptable degradation of metal components. A total of 15 metals and 7 aqueous or semiaqueous cleaners were evaluated.

The results show that aqueous cleaners can be used to replace traditional ODCs in both ultrasonic and soak cleaning processes with one major limitation. This limitation is that no single aqueous or semiaqueous cleaner studied in this program was able to replace CFC-113 for cleaning all metals. Aqueous cleaners must be matched to the specific metal that is being cleaned. Compatibility criteria and compatibility tables were established for determining metal/cleaner pairs that can be used without causing unacceptable degradation of the metal surfaces.

Contract Final Report

Data Item No. A004

Contract No. F04606-89-D-0034-Q805

METALS-DETERGENT/CLEANER COMPATIBILITY STUDY

to

THE AEROSPACE GUIDANCE AND METROLOGY CENTER

Newark Air Force Base

January 14, 1993

Introduction and Background

The Aerospace Guidance and Metrology Center (AGMC), located at the Newark Air Force Base (NAFB) in Newark, Ohio, repairs and services inertial navigation and guidance equipment for the United States Air Force and other Department of Defense (DoD) agencies. Thousands of these delicate and sophisticated electromechanical devices are repaired each year at the Center. The current repair and service processes include cleaning of these devices with chloroflurocarbons and chlorinated hydrocarbon cleaners. Because these cleaning chemicals have been classified as ozone depleting chemicals (ODCs), AGMC has instituted several programs to identify environmentally friendly alternatives. Aqueous-based chemicals and detergents have become the cleaners of choice for replacing the ODCs.

Aqueous cleaning is currently used most widely in the metal cleaning and electronics industries. Many believe aqueous cleaning is a mature technology and is being adopted by increasing numbers of companies to clean metals. However, aqueous cleaning is inherently more corrosive to metals than is hydrocarbon-based cleaners. Accordingly, users of aqueous cleaners should conduct tests to ensure that replacing hydrocarbon-based cleaners does not result in unacceptable corrosion of metals as a result of the cleaning process.

This report describes the results of Battelle's compatibility study of fifteen metals and seven aqueous* and two nonaqueous cleaners when used in sonication and soaking cleaning methods.

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* Aqueous cleaners refer to cleaners that either contain water or are diluted with water when used; nonaqueous refers to cleaners that do not contain water when used.

Objective and Scope

The objective of these tests was to experimentally evaluate the degradation potential of aqueous cleaning methods on metals used in inertial navigation and guidance equipment and other components and compare the results obtained with CFC-113, the ODC currently used for much of the cleaning.

The scope of this study included 15 metals that comprised a subset of a larger list of metals that are cleaned by AGMC. The metals selected for testing represent either the family of materials most often cleaned, and therefore of greatest importance to AGMC, or alloys that are judged likely to be the most susceptible to corrosion attack.

The scope of the cleaning solutions included nine specific cleaners requested by AGMC. Most of these cleaners were used in the previous Battelle study on the effect of potential degradation of polymeric structural adhesives.

To accomplish the program's objectives, a statistical approach was used to maximize the information content of the data collected. This approach included a series of four major experiments that were conducted on metal coupons that were exposed to various cleaning agents and methods and then evaluated for various types of corrosion damage.

The initial scope of this study was to provide guidance for AGMC's cleaning operations. However, as the program progressed it was recognized that the information collected here would be valuable to other Air Force operations and, indeed, any industries that are involved in selecting alternatives to ODC cleaners.

Program Approach

An experimental approach was chosen to extract as much information as possible while using the minimum amount of laboratory testing. To accomplish this, a sequential test plan was followed based on a statistically designed experimental matrix. The sequential nature of the experiments permitted aggregation of information based on building blocks laid down on earlier experiments. The use of consecutive experiments permitted changes to be incorporated into subsequent experiments thereby allowing a flexibility into the design that otherwise would not be possible if all the experiments had been conducted concurrently.

Selection of Cleaners

The nine cleaners chosen for this study were based on selections used in previous studies for AGMC. The cleaners represented several classes of aqueous and nonaqueous cleaners including aqueous detergents, semiaqueous cleaners, and nonhalogenated hydrocarbons (see Table 1). Classifying these cleaners was difficult due to their proprietary nature. In most cases, only the information on the material safety data sheets (MSDS) was available, and these listed only the presence of possible hazardous materials. Another complication was the misidentification of the cleaner by the manufacturer; for example, an aqueous cleaner is technically a detergent only if it contains a surfactant. An aqueous cleaner without a surfactant should only be called a cleaner. Cleaners could be classified into aqueous, and nonaqueous. These categories could be further divided into different classifications. For example, aqueous cleaners are divided into acidic, emulsion or semiaqueous, and alkaline cleaners. The aqueous cleaners could be classified as to whether they are ionic or non-ionic in nature. The nonaqueous cleaners could be divided into halogenated and nonhalogenated cleaners.

Types of Cleaners

This section describes the various classifications of alternative cleaners used by the military and industry in the attempt to replace ODCs such as 1,1,1, Trichloroethane (TCA) and

Table 1. List of detergents/cleaners

Detergent/Cleaner Name	Cleaner Type	Manufacturers' Recommended Cleaner Conc. Ratio (vol. %)	Ingredients listed in MSDS	Manufacturer
Deionized water[a]	Aqueous Control	not applicable	not applicable	
Versa-Clean	Aqueous non-ionic Detergent	1:30 (3.2)	1. Polyethylene glycol nonylphenol ether 2. Cocoamide DEA	Ken Crowe, Inc.
Brulin 815 GD	Aqueous Alkaline	1:20 (4.8)	None listed	Brulin & Company, Inc.
Intex 8125	Aqueous Alkaline (mild)	1:20 (4.8)[b] 1:10 (9.1)	1. Dipropylene Glycol Methylether	EZE Products, Inc.
EZE 240	Aqueous Alkaline Emulsifier	1:40 (2.4)	1. Hexylene Glycol 2. Ethanolamine	EZE Products, Inc.
EZE 244	Nonhalogenated Alkaline Emulsifier	Neat	1. Monoisopropanolamine 2. Cyclohexanol	EZE Products, Inc.
Intex 8284	Acid Burnishing Detergent	1:20 (4.8)	None listed	EZE Products, Inc.
Kyzen Aquanox X2031	Semiaqueous/nonlinear Alcohol Detergent	Neat	Ethanol, 2-amine	Kyzen Corporation
PF Degreaser	Nonhalogenated hydrocarbon	Neat	None listed	P-T Technologies, Inc.
CFC-113	Chlorofluorocarbon Control	Neat	1,1,2-trichloro-1,2,2-trifluoroethane	Various vendors

(a) Type E-2 Electronic grade water, resistivity = 17.5 MΩ·cm
(b) 1:20 for sonication, and 1:10 for soaking

CFC-113. In this study, CFC-113 was used as a control or benchmark against which the other cleaners were compared. Electronic grade, Type E-2 water, as specified by a recently proposed ASTM standard, also was used as a control for purposes of comparison.

Aqueous Cleaners

According to D'Ruiz* there are three types of aqueous detergents: acidic, emulsion, and alkaline. The following paragraphs briefly describe these types of aqueous detergents and is based on information obtained from D'Ruiz.

Acidic Cleaners. Acidic cleaners are not commonly used to clean components in the metal and electronics industries because they attack the substrates of materials used in these industries. Acidic cleaners could be useful in cleaning aluminum, which is otherwise susceptible to etching when cleaned with strong alkaline detergents. However, some acidic cleaner manufacturers do not recommend their products to clean aluminum, magnesium, titanium, or other reactive metals. Accordingly, manufacturer's recommendations should be consulted when using these types of cleaners on metals. Intex 8284 used in this study is an acid cleaner.

Emulsion Cleaners. Emulsion cleaners, also known as semiaqueous cleaners, are aqueous cleaners that contain emulsifiable solvents and consist of a solvent suspended in a water-based cleaning solution. These cleaners are used primarily to clean parts contaminated with organics. Solvents typically used in these cleaners include alcohol, methylene chloride, methyl chloroform, or, most commonly, 2-butoxy ethanol. Though these cleaners are quite effective, their use is often restricted due to the difficulty in disposal of spent emulsions and the strict government emission regulations on volatile organic compounds (VOCs). Many of these cleaners are used neat, and EZE 244 and Kyzen Aquanox X2031 used in this study probably fall in this category of cleaners.

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* D'Ruiz, Carl D. *Aqueous Cleaning as an Alternative to CFC and Chlorinated Solvent-Based Cleaning*, Park Ridge, New Jersey: Noyes Publications, 1991.

Alkaline Cleaners. These cleaners are presently considered the best substitute for halogenated solvents used in degreasing metals and electronic components. Alkaline cleaners have been formulated to remove the same contaminants that are currently removed by chlorinated solvents. The most common active ingredients in alkaline cleaners are anionic and non-ionic surfactants. They also contain builders to suspend soils and prevent redeposition. Corrosion inhibitors such as silicate salts are often added to minimize the effect of alkaline cleaners on metal surfaces.

Aqueous alkaline cleaners are used in various concentrations, but a typical concentration range for liquid cleaners is 1 to 10 percent by volume in water. Although hundreds of alkaline cleaners are commercially available, most of these products need to be tested to ensure that they are effective for specific applications and that they minimize potential corrosion or residue. The alkaline cleaners used in this study include EZE 240, Brulin 815 GD, and Intex 8125.

Nonaqueous Cleaners

There are perhaps as many nonaqueous cleaners as aqueous ones. PF Degreaser was chosen to represent the nonhalogenated hydrocarbon cleaners. This cleaner has been used extensively to degrease aircraft components.

Selection of Metals

AGMC originally provided a list of 32 different metals for evaluation. These metals were encountered by AGMC during the servicing, repairing, and cleaning of precision instruments for the Air Force. The list was shortened by eliminating metals that were either infrequently encountered, exceptionally corrosion resistant (such as palladium or platinum), or whose corrosion behavior would be similar to another alloy of the type included in the list. An example of the last case is AA6061 and AA6063, which differ only slightly in their silicon and magnesium content.

The final list of metals used in this study is shown in Table 2. These metals included two aluminum alloys (AA2017 and AA6061), an instrument-grade beryllium, three copper-base alloys (CDA172, CDA182, and CDA260), an alloy steel* containing 1.4 percent chromium (C52100), two stainless steels (Types 304 and 316), two "electronic" alloys (4750 steel and HyMu77), one solder (60Sn/40Pb), and a corrosion resistant nickel base alloy (Inconel 600). In addition, two coatings were included for testing, namely an anodized coating over aluminum alloy 2017 and gold plate over cartridge brass (CDA260). The elemental compositions of these metals are listed in Appendix A.

Table 2. List of tested metals

Name of Metal or Coating
4750 Steel
Aluminum 2017-T0 (anodized per MIL-A-8625)
Aluminum 2017-T0 (nonanodized)
Aluminum 6061-T4
Beryllium per MC-1400 Grade A
Beryllium Copper (CDA172)
Cartridge Brass (70Cu/30Zn) CDA260
Chromium Copper (CDA182)
Chromium Steel (C52100)
Gold-Plated Brass (CDA 260) per MIL-G-45204
HyMu77
Inconel 600
Solder (60Sn/40Pb)
Type 304 Stainless Steel
Type 316 Stainless Steel

* Alloy steels contain Mn, Si, or Cu in quantities greater than typical carbon steels or they have specified ranges or minimums for other alloying elements.

Related Reports

There are several related reports prepared by Battelle and issued to AGMC that may be of interest to the reader. These include:

1. "A Method For Cleaning Performance Evaluation Using Stable Isotopes", by S.P. Chauhan et al., Contract No. F09603-90-D-2217/Q802, August, 31 1992.

2. "Experimental Evaluation of the Adhesive Degradation Potential of Aqueous Cleaning Processes", by Dennis Miller, Contract No.F09603-90-D-2217/Q804, January 25, 1993.

3. "Identification of Biodegradable/Environmentally Compatible Methods for Epoxy Removal -- Phase I, by Robert P. Collier, Elizabeth Drotleff, and Dyryodhan Mangaraj, Contract No. F04606-89-D-0034/Q804, August 6, 1993.

4. "Biodegradability of Detergents and its Effects on Municipal Activated Sludge", by Bruce Alleman, Contract No. F04606-89-D-0034/Q806, September 14, 1993.

Experimental Methods

This section describes the experimental methods used to test the alloys' compatibility with the detergents/cleaners used in this study. Four major experiments, numbered one to four, were performed to determine which metals are compatible with each detergent/cleaner.

Experimental Approach

Experimental Design

A statistical design for an experiment provides a "blueprint" for the trials to be run and the data to be collected. The assumed empirical model dictates the appropriate design. Each trial within a design is a set of values (levels) of the independent variables corresponding to which observation of each dependent variable (also called a "response") is tabulated. In this evaluation, each trial was run in triplicate (except for beryllium which was run in duplicate). Thus, a row in the design actually represented three coupons in the laboratory. Unexposed control metal coupons were also evaluated. The unexposed controls are not shown in the designs presented below.

The independent variables that were controlled experimentally included metal, cleaner, cleaning method, temperature, and concentration of cleaning solution. The independent variables are described in Table 3. X_1 is metal and has 15 levels. That is, for each trial, X_1 will be one of the 15 metals under evaluation. X_2 is detergent/cleaner and has 9 levels, including deionized water and CFC-113 as controls. X_3 is cleaning method and has two levels: sonication using the standard Sonic Systems ultrasonic cleaner for 5 minutes and soaking for 16 hours to approximate life-cycle effects. Shorter times of one hour and ten minutes for soaking times were added later in the tests. The fourth independent variable, X_4, is temperature of the bath at the start of the cleaning process. Temperatures of 120 F and 155 F were used. X_5 is concentration of the detergent/cleaner and had up to four levels based on the range of concentrations recommended by the cleaner vendor. Five of the cleaners were tested only at one concentration level, namely 100 percent, because either of manufacturer's recommendation or they can be used only at one concentration. These were deionized water, EZE 244, Kyzen X2031, PF Degreaser, and CFC-113.

The study consisted of four major experiments. These are described in detail in Appendix B, and their logical flow diagram is illustrated in Figure 1. The first experiment was directed toward characterization of degradation under the assumption that the conditions selected may cause degradation in the laboratory. The second experiment looked specifically at the effect of concentration and its mathematical form. The third experiment generalized the results of the first experiment to four additional, commonly-cleaned metals. The final experiment evaluated the degradation of less commonly cleaned or more corrosion-resistant metals under the most hostile conditions determined by the previous three experiments.

Table 3. Independent variables of experimental design

Variables	Description	Number of Levels
X_1	Metal Each level represents a distinct metal to be tested. See Table 2 for list of metals. The metals are designated 1 through 15.	15
X_2	Detergent/Cleaner and Control Solutions Each level represents a distinct cleaning solution and two controls. See Table 1 for list of detergents.	9
X_3	Cleaning Methods The two methods of cleaning are sonication and soaking. (S) = 16-hour, 1-hour, or 10-minute soaking (U) = 5-minute sonication	2
X_4	Temperature Levels selected are 120 F and 155 F to cover a feasible range for this quantitative variable.	2
X_5	Detergent/Cleaner Concentration Up to four levels were evaluated during the course of the study. In some designs, only the lowest and highest concentrations were run and in later designs only the highest concentrations were used.	1 to 4

The total program consisted of over 380 trials run in triplicate (or duplicate) for a total of over 1000 coupons. This compares quite favorably to the 1512 trials and over 4500 coupons that would have been required to run the full factorial.

A review meeting was held at the end of each major experiment to review its results and decide what changes should be made in the subsequent tests.

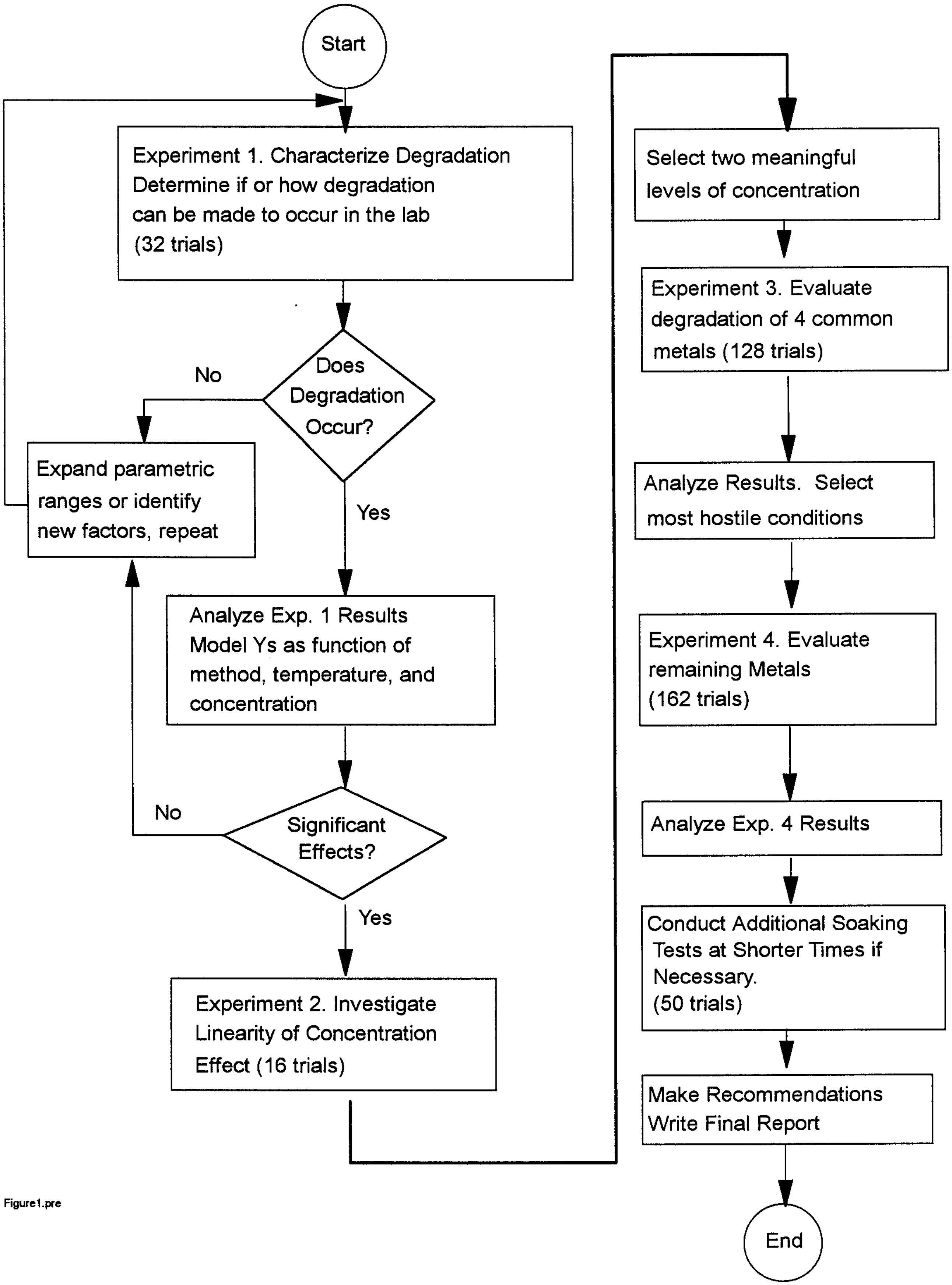


Figure 1. Logical flow of experimental plan

Implementation of Design

The overall plan for implementing the coupon tests is outlined in Table 4. The details of the preparation of the metal coupons are given in Appendix C.

Table 4. Implementation plan

Operation
Coupon Acquisition and Preparation
Baseline and Control Conditions
Exposure of Coupons to Cleaning Solutions Soaking Sonication
Coupon Drying Procedure
Final Coupon Weighing and SQM Readings
Coupon Corrosion Behavior Evaluation

Compatibility Criteria

Several types of measurements were made on the metals to determine whether they were compatible with the various cleaners. Compatibility is defined as a metal undergoing an acceptable level of degradation when exposed to a cleaner for a specified time at a specified temperature using a specified cleaning method. An "acceptable level" of degradation is not an absolute quantity but rather is based on various criteria, when taken as a whole, would allow a metal to be used in a cleaner without any deleterious changes to its surface properties. What is an acceptable level of degradation for one application or user may not be acceptable for another. An example may be a user that produces polished metal surfaces for optical instruments requiring one level of acceptable degradation compared with a user that removes paints or degreases aircraft engine-oil heat-exchangers who has an entirely different standard for degradation. In the first case, the user clearly will require a much lower level of degradation to a metal's surface than in the latter case.

An attempt was made to minimize the degree of subjectivity associated with the assessment of degradation. The issue of cleanliness is open to even more subjectivity. This was accomplished by basing most of the degradation criteria on an easily measurable quantity, namely weight loss, which is discussed in the following section. In addition to weight loss, visual examination of the coupons for evidence of corrosion and color change was also used to corraborate and complement the weight change data.

Weight Loss Measurement

Weight loss is used in calculating corrosion rate*, which is the single most widely used parameter to compare and measure a metal's performance in a particular environment. However, in this study, corrosion rate was not judged to be meaningful because of the very short exposure times involved (5 minutes to 16 hours). Corrosion rates often are initially higher when metals are first exposed to a corrosive environment and then gradually decrease to an equilibrium value. Generally, several weeks to months of exposure are required before an equilibrium condition occurs.

One disadvantage of using weight loss, or more specifically percent weight loss (see Equation 1), in evaluating metal degradation is that it does not take into account how

$$\mathit{Percent\ Weight\ Loss} = \left(\frac{\mathit{Initial\ Weight} - \mathit{Final\ Weight}}{\mathit{Initial\ Weight}}\right)100 \tag{1}$$

* A metal's exposed surface area, density, and exposure times are the additional parameters needed to calculate corrosion rate from weight loss data.

that weight loss is distributed over the surface of the metal. For example, a metal undergoing primarily pitting attack, a form of localized attack, may have almost all of its weight loss confined to very small areas on the surface. This occurs most often in stainless steels and aluminum alloys and other alloys that tend to form passive protective films.

Another disadvantage is that a metal may appear to gain weight, resulting in a *negative* weight loss value according to Equation (1), and still have undergone corrosion. This occurs most often when the corrosion product is insoluble in the test solution and adheres to the metal's surface, or when the solution deposits a film on the surface. In the first case, the corrosion product needs to be removed by descaling chemicals that selectively dissolve oxides and do not attack the base metal in order to get a true weight loss measurement. In almost all cases, the corrosion product or deposited film will be visible and will discolor the metal's surface. To account for these factors that can cause discrepancies in weight loss measurements, visual observations (discussed in the **Visual Inspection Techniques** section) were made on the surfaces before and after testing, and documented by photography. In addition, the cleaner solution was analyzed in certain cases for the presence of dissolved metals to aid in determining whether degradation of the metal occurred (see **Chemical Analysis of Cleaner Solution**).

Visual Inspection Techniques

Visual inspection techniques used to examine the coupons included optical microscopy. Typical examinations of corrosion coupons are usually made at a magnification of 20 to 30X, but in this study a Nikon stereo microscope with a magnification of 200X was used to examine the surfaces. The same location on each coupon was examined to ensure a degree of consistency from one coupon to another. The location examined was in the center of the coupon on the side opposite the stenciled identification number. The higher magnification was used to enable the detection of the onset of corrosion attack in its earliest stages. The corrosion attack would be either general or pitting attack or both.

Pit Depth Measurement. The higher magnification also allowed pit depths to be measured to an accuracy of 0.05 mils (1.3 μm). Pit depths were measured by the focal-plane method. In this method, the vertical distance displaced by a coupon is measured by the microscope's stage movement as one focuses on the top and bottom of an observed pit. The measured distance is displayed on a digital readout from a linear variable differential transformer (LVDT) that is attached to the microscope's stage.

Color Change. Color change was used as an additional criterion for whether a metal's compatibility with a cleaner was in question. Quantifying color change was subjective, though in many cases it was very obvious, as when aluminum turned from its normal color to black. Almost all the color changes were uniform in appearance. The more subtle changes in color were judged significant if the coupon in question could easily be spotted when it was placed among six other untested coupons on a laboratory bench under normal fluorescent lighting. In the few cases where spotting occurred, that is, when only small areas of a coupon appeared to have undergone a color change or staining, a more detailed examination of other parts of the surface was undertaken to determine if other signs of corrosion could be found.

Surface Quality Measurements Using O.S.E.E.

The Optically Stimulated Electron Emission (O.S.E.E.) technique was used during the initial experiments on the metals as an additional means of measuring metal surface degradation after exposure to cleaners. This technique is based on the photoelectric effect of metals emitting electrons when they are illuminated with ultraviolet light. Traditionally, this technique requires the metal to be in a vacuum, but recent technology has allowed the measurements to take place in open air. The emitted electrons are collected and measured as a current which is then displayed as a number between 0 and 1000 (the larger the displayed number, the higher the number of emitted electrons).

Any nonconductor or film on the surface would interfere with the number of electrons emitted and therefore result in a lower displayed number. This technique works best if the initial and final surfaces differ only by the presence or absence of a surface contaminant. However, if the surface morphology itself changes due to its exposure to, say, a cleaner, then the final O.S.E.E. readings are meaningless. This was the case in this study where several of the metals, particularly the aluminum alloys, underwent pitting or excessive general corrosion in some of the cleaners. Accordingly, this method was abandoned, and its results are not reported because it could not be used for all the metals tested.

Chemical Analyses of Cleaner Solutions

Samples of cleaner solutions (approximately 10 ml each) were taken before and after they were used in testing the various metals. These samples were analyzed by the inductively coupled plasma (ICP) technique in cases where the metals gained weight after cleaning, but no change to the coupon's surface was visible. As discussed earlier, coupons could have undergone corrosion and still have gained weight. Detection of the constituents of the coupons's metal in the cleaner solution after testing, when they were not present before testing, would indicate that corrosion did in fact occur.

Results

The summary of the results of the experimental evaluations of the metals tested in the cleaners is presented in this section. Details of the results including statistical calculations, tabulated weight loss data, graphs of the weight loss data, micrographs of the metals exhibiting degradation, and chemical analyses are shown in the Appendices.

Statistical Analysis Summary of Weight-Change Data

This section summarizes the statistical analysis results of the weight change data for the four major parts of the study, namely Experiments No.1 through No.4.

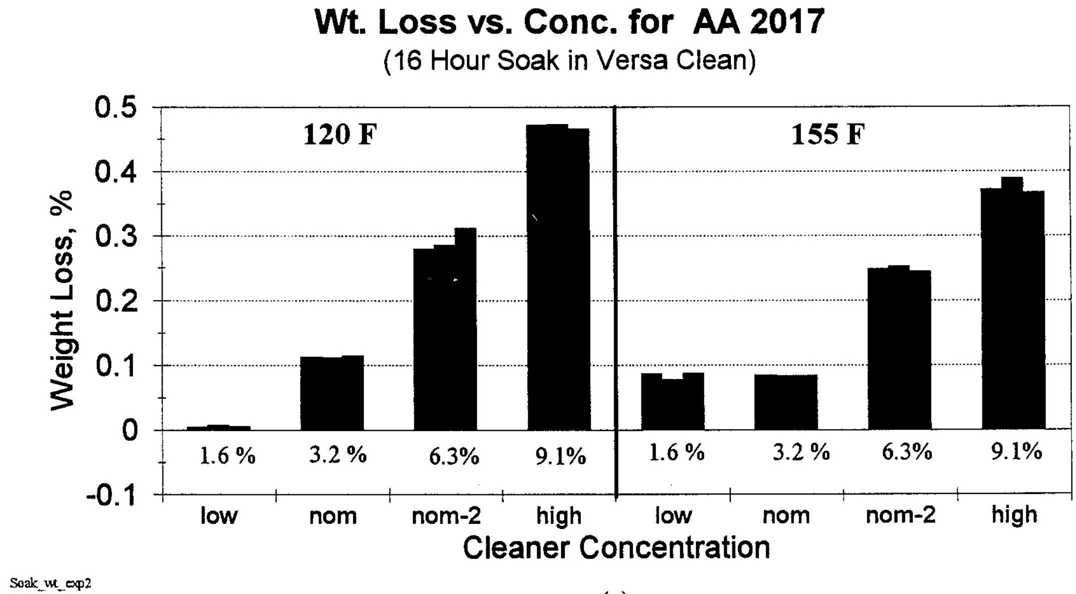
Characterization of Degradation (Experiment No. 1)

A statistical analysis was conducted of the weight loss data of the aluminum coupons. The analysis indicated that the different cleaners caused statistically significant differences in weight change. These results permitted the program to proceed to the next step of investigating the dependency of weight loss on cleaner concentration. The details of the statistical analysis are shown in Appendix D.

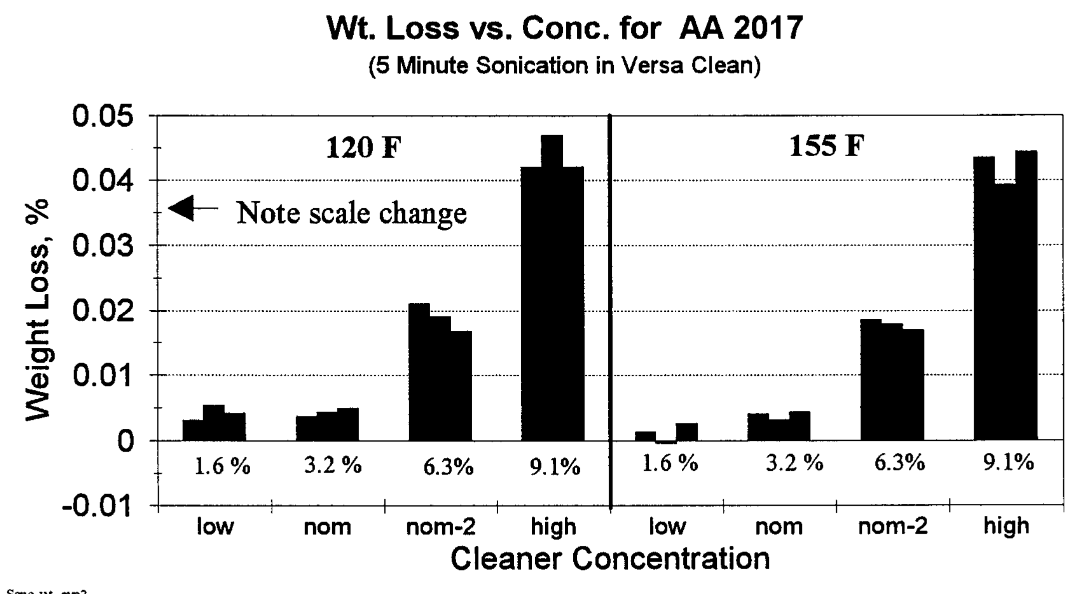
Weight Loss as a Function of Cleaner Concentration (Experiment No. 2)

Figure 2 shows the bar charts of the weight loss data for the full factorial design (see Appendix B) of AA2017 tested in Versa Clean at two temperatures, four concentrations, and two cleaning methods. The weight loss is seen to generally increase with increasing concentration for both cleaning methods, though the percent weight loss in the 16-hour soak is approximately ten times greater than in the 5-minute sonication. A regression analysis of the sonication data and the soaking data indicated that the best fit was found using the natural log of the concentration (see Appendix E). The results of this regression analysis for the soaking data is shown in Figure 3 in the form of a surface plot. The surface plot of the regression analysis of the sonication data is similar to the soaking data's surface plot. An examination of the surface plot clearly shows that the concentration effect is much greater than the temperature effect.

For constant temperatures, there is an excellent fit for a linear dependency of weight-loss on concentration. Figure 4 shows the linear regression fits for the soaking data and sonciation data for aluminum AA2017 in Versa Clean at 120 F. Based on this analysis, the assumption was made that the other reactive metals would behave similarly. In particular, it was assumed that the degradation would increase, if not linearly, at least monotonically, with increasing cleaner concentration. Therefore, the next statistical analysis was conducted on four additional metals using the partial factorial shown in Appendix B where the concentration levels chosen for testing represented the low and high values for each cleaner. The highest concentration for Versa Clean was chosen to be 6.3 vol. percent instead of the original 9.1 vol. percent for the remainder of the tests. The personnel at AGMC found the 6.3 vol. percent level of Versa Clean to be the highest concentration necessary to remove the soils and contaminants from their instrumentation.



(a)



(b)

Figure 2. Bar charts showing percent weight loss of AA 2017 soaked in Versa Clean for 16 hours (a) and after the five-minute sonication test (b).

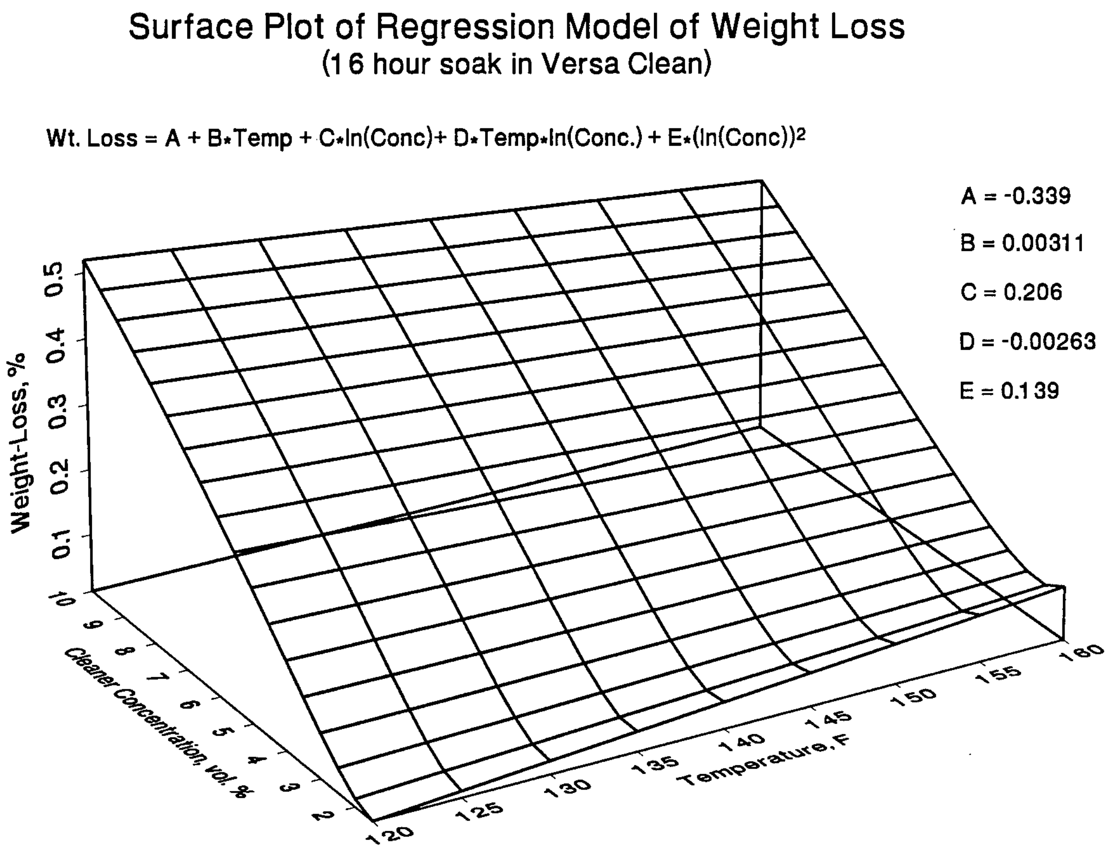


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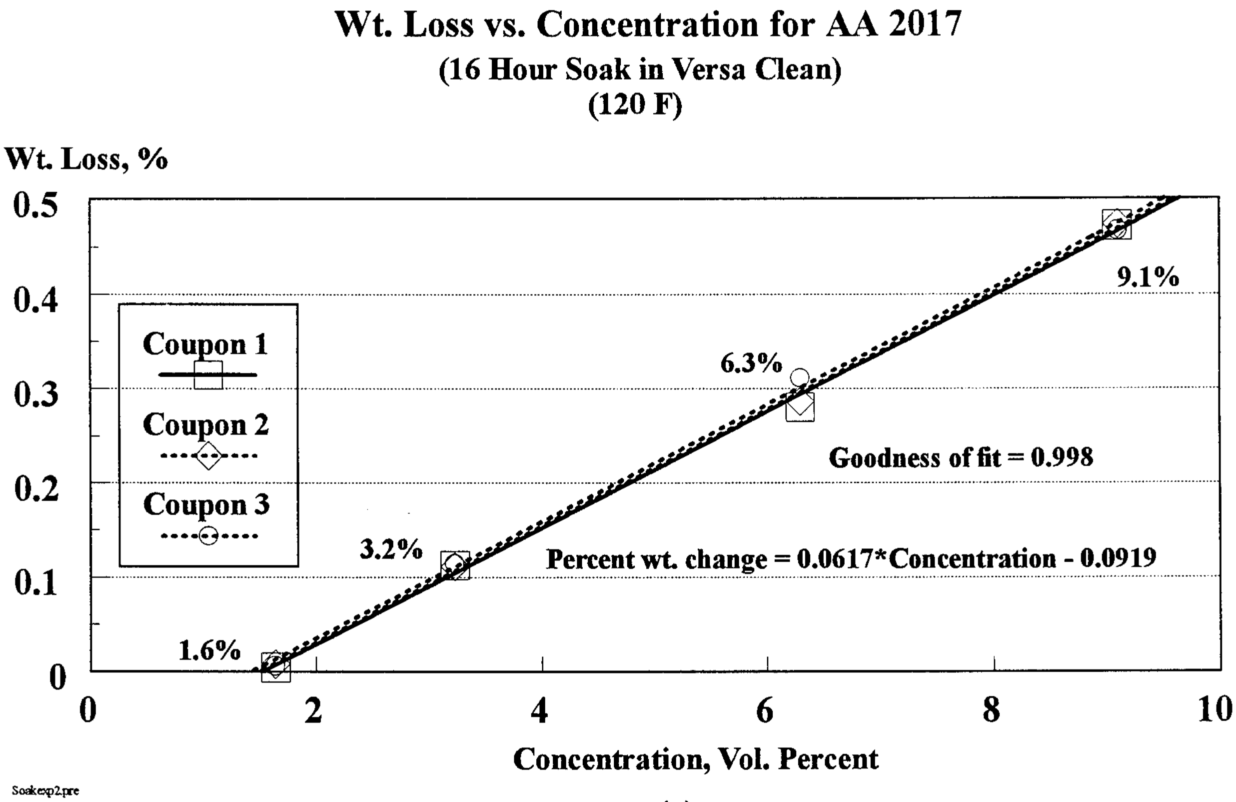
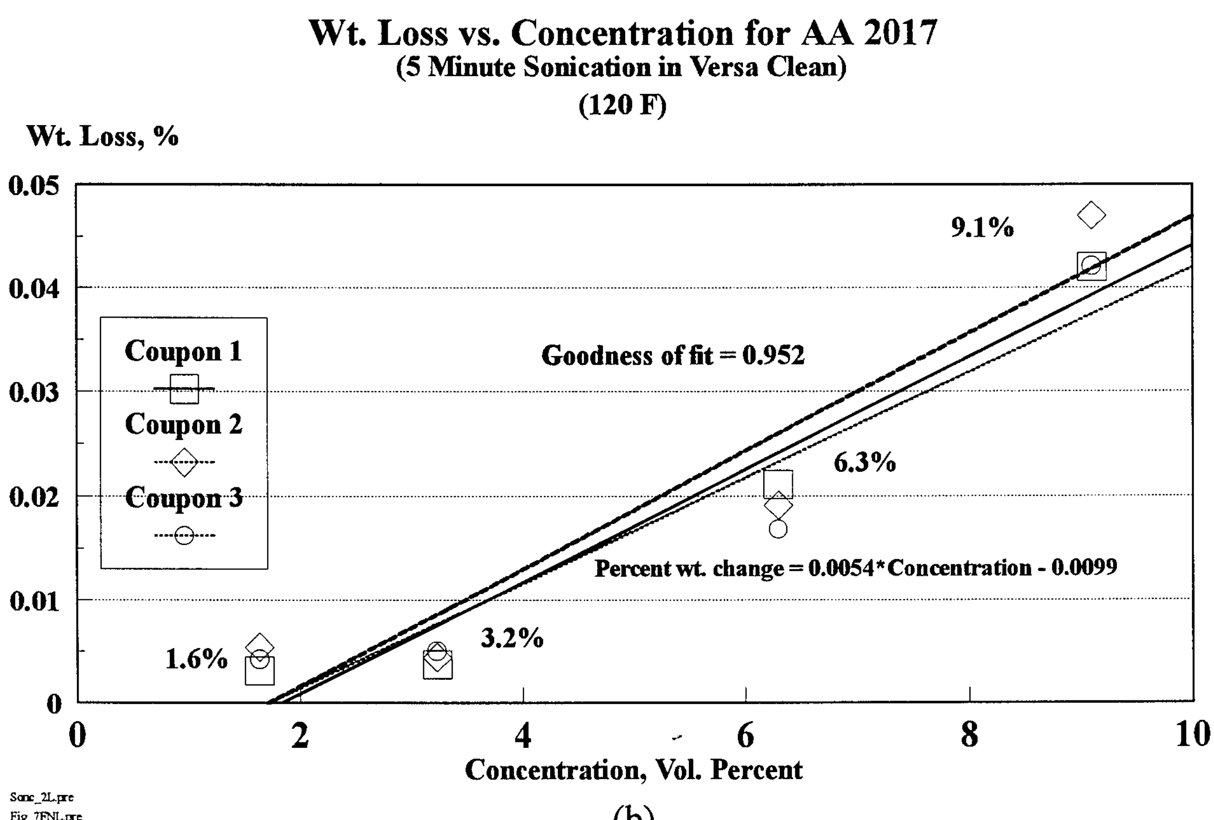
Figure 3. Surface plot of regression analysis model of AA 2017 soaked in Versa Clean for 16 hours.



(a)



(b)

Figure 4. Linear regression fit of weight loss of AA 2017 vs. concentration in Versa Clean at 120 F for soaking (a) and sonciation (b).

Statistical Determination of Most Hostile Conditions (Experiment No. 3)

A statistical analysis of the weight loss data for 4750 steel, anodized aluminum AA2017, beryllium, and cartridge brass metals was conducted for both the 16 hour soaking and five minute sonication methods in the third experiment. The resulting regression equations are shown in Appendix F.

Sonication Method. The regression analysis for sonication showed no statistically significant effects of temperature or concentration. Anodized aluminum AA 2017 showed a significant degradation while the other alloys did not. The only statistically significant cleaner effect for sonication was associated with EZE 244, which caused a much greater weight loss than CFC-113.

Sixteen Hour Soaking Method. In the soaking method, the temperature-concentration interaction was statistically significant. Temperature, concentration, and the square of the concentration were not found to be important compared with beryllium as a control. Anodized aluminum 2017 showed a considerable significance while the other metals did not. The cleaner control used was CFC-113. Versa Clean, Brulin 815 GD, and Intex 8284 produced significantly greater weight loss of the four metals tested in Experiment No. 3 compared with CFC-113. EZE 244 showed more weight loss than CFC-113, but was not statistically significant at the 95 percent level.

The effect of soaking and sonication for combinations of temperature and concentration at high and low levels were calculated using the model shown in Equation 2. The results indicated that the most hostile condition for the coupons appeared to be low temperature and high cleaner concentration for all the tests except for sonication of Experiment No. 3. However, the sonication data of Experiment No. 3 was disregarded because (a) the observed variations for the sonication data were small, (b) temperature and concentration factors were not significant, and (c) the modelling showed that most of the sonication effect observed was random. Accordingly, the most hostile condition for causing degradation of the metals exposed to the cleaners was when the temperature was 120 F and the highest concentration of the cleaner (where applicable) was used.

$$Wt.\ Loss = B_0+\sum_{i=1}^{7} B_iD_i+\sum_{j=8}^{10} B_jM_j+B_{11}C+B_{12}T+B_{13}TC+B_{14}C^2 \tag{2}$$

Bs are fitted coefficients,
D_i are indicator variables* for the cleaners (CFC-113 used as a control),
M_j are indicator variables for the metals (beryllium used as a control),
C = concentration (transformed to -1, +1 scale),
T = temperature.

The most likely reason the lower temperature would result in a more aggressive cleaner for metals than at a higher temperature is that the oxygen solubility decreases in solution with increasing temperature**. All things being equal, a higher oxygen content would allow the corrosion reaction to proceed more readily. The effect of greater oxygen content is apparently more important than the expected increase in corrosion damage with increasing temperature. In addition, the effect of concentration was found to be greater than the effect of temperature on degradation.

Statistical Analysis of Metals Tested in Most Hostile Conditions (Experiment No. 4)

A regression analysis (see Appendix G for calculations) was performed on the metals tested under the most hostile conditions, namely 120 F, and at the high cleaner concentration shown in Table B-4. The results of these analyses in conjunction with the weight loss data and visual observations were used to construct a set of Compatibility Summary Tables showing which cleaners were compatible with each of the metals tested.

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* An indicator variable is a discrete quantity which equals one when the indicated cleaner or metal is present and zero otherwise. Fitted coefficients are shown in Appendix F.

** Heidersbach, Robert H., "Marine Corrosion", in *Metals Handbook Ninth Edition*, volume 13, ASM International, pg. 895, 1987. See Appendix K for graph of oxygen solubility in water versus temperature.

Results of One-Hour and Ten-Minute Soak Periods

Alloys that exhibited degradation after their 16-hour soak in a cleaner were tested again (using new coupons) at shorter soak periods, namely one hour and ten minutes (see Appendix C for test procedure). Some of the less corrosion resistant alloys, such as AA 2017, AA 6061 and solder, continued to exhibit degradation in some of the more aggressive cleaners at one-hour soaking and even at ten-minute soaking. Weight loss versus time was graphed for alloys that were tested at three different soak times in a cleaner. Data for the additional soak time tests are presented in Appendices H and I, and the results summarized in the Compatibility Summary Tables.

Compatibility Summary Tables

Tables 5 and 6 summarize the compatibility of the metals with the various cleaners for the soaking and sonication cleaning methods, respectively. These tables were based on the coupon's weight change data (Appendix H and I) and on visual observations of their surfaces (Appendix J). As mentioned in the **Compatibility Criteria** section, compatibility was based on the coupons meeting several conditions. These conditions are the following:

- Weight loss less than 0.01 percent
- No uniform color change
- Pits no deeper than 0.0005 inch (0.5 mil)
- No visible general corrosion at 200X.

Table 5. Compatibility summary table for soaking ≤ 16 hours between 120 and 155 F[(a)]

ALLOY	Versa Clean	PF Degreaser	EZE 240	EZE 244	Brulin 815 GD	Intex 8125	Intex 8284	Kyzen X2031	DI H_2O	CFC 113
4750 Steel	OK	OK	nt	OK	OK	60 min.	60 min.	OK	OK	OK
AA2017 (anodized)	10 min.	OK	nt	OK*	OK?	60 min.	NOT	OK	OK	OK
AA2017	10 min.	OK	OK*	NOT	OK	60 min.	60 min.	OK	60 min.	OK
AA6061	NOT	OK	nt	NOT	OK	60 min.	60 min.	OK	60 min.	OK
Beryllium	OK	OK	nt	OK	OK	OK	60 min.	OK	OK	OK
Beryllium Copper	60 min.	OK	nt	60 min.	60 min.	60 min.	60 min.	OK?	OK	OK
Cartridge Brass	60 min.	OK	nt	10 min.	60 min.	OK	60 min.	NOT[(c)]	OK	OK
Chromium Copper	OK**	OK	nt	10 min.	60 min.	OK	60 min.	10 min.	OK	OK
Chromium Steel	OK	OK	nt	OK	OK	10 min.	NOT	OK	10 min.	OK
Gold-Plated Brass	OK	OK	nt	OK	OK	OK	OK	OK	OK	OK
HyMu77	OK	OK	nt	OK	OK	OK	NOT	OK	OK	OK
Inconel 600	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Solder[(b)]	10 min.	60 min.	nt	10 min.	10 min.	NOT	10 min.	60 min.	60 min	60 min.
Type 304 S.S.	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Type 316 S.S.	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

OK = compatible up to 16 hours of soaking, 60 min. = compatible up to 60 minutes of soaking, nt = not tested,
10 min. = compatible up to 10 minutes of soaking, OK? = borderline compatible at 16 hours, NOT = not compatible for any soak time,
(a) PF Degreaser and CFC-113 tested only at 120 F and 115 F, respectively.
(b) Solder not tested in 16 hour soak.
(c) White reaction product film was left on coupon's surface after all soak times.
* Compatible only at 155 F
** Compatible only at two percent concentration.

Table 6. Compatibility summary table for 5-minute sonication[a] between 120 and 155 F[b]

ALLOY	Versa Clean	PF Degreaser	EZE 240	EZE 244	Brulin 815 GD	Intex 8125	Intex 8284	Kyzen X2031	DI H_20	CFC 113
4750 steel	OK	OK	nt	OK	OK	OK	OK	OK	OK	OK
AA2017 (anodized)	NOT*	OK	nt	NOT	NOT	OK	NOT	OK	OK	OK
AA2017	NOT*	OK	OK	NOT	OK	OK	OK	OK	OK	OK
AA6061	NOT*	OK	nt	NOT	OK	OK	OK	OK	OK	OK
Beryllium	OK	OK	nt	OK	OK	OK	OK	OK	OK	OK
Beryllium Copper	OK	OK	nt	OK	OK	OK	OK	OK	OK	OK
Cartridge Brass	NOT*	OK	nt	OK	OK	OK	OK	OK	OK	OK
Chromium Copper	OK	OK	nt	OK	OK	OK	OK	OK	OK	OK
Chromium Steel	OK	OK	nt	OK	OK	OK	OK?	OK	OK	OK
Gold-Plated Brass	OK	OK	nt	OK	OK	OK	OK	OK	OK	OK
HyMu77	OK	OK	nt	OK	OK	OK	OK	OK	OK	OK
Inconel 600	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Type 304 S.S.	OK	OK	nt	OK	OK	OK	OK	OK	OK	OK
Type 316 S.S.	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

<u>NOT</u> = not compatible, <u>OK</u> = compatible for 5-minute sonication, <u>OK?</u> = borderline compatible, <u>nt</u> = not tested

(a) Nominal sonication power = 600 W at 40 kHz, 100 W per gallon

(b) PF Degreaser and CFC-113 tested only at 120 F and 115 F, respectively

* OK at two percent concentration only.

Summary of Visual Observations and Loss Change Data of Tested Metals

This section summarizes the degree of mode of degradation each alloy experienced after its exposure to the sonication and soaking cleaning methods. The summary is based on the microscopic and macroscopic inspection of the alloys and on their weight loss.

4750 Steel and Chromium Steel

These alloys did not exhibit any visible degradation in the 5-minute sonication test with the possible exception of chromium steel in Intex 8284. Slight localized attack on chromium steel in Intex 8284 occurred along the grinding marks, but the penetration was less than 0.5 mils deep (see Appendix J).

These alloys did exhibit degradation in the soak test in both Intex 8125 and 8284. In addition, chromium steel showed degradation in deionized water. General corrosion was the mode of attack on both these alloys as shown in photographs in Appendix J. In the case of chromium steel soaked in the Intex cleaners, all the grinding marks were corroded away. Figure 5 shows the appearance of coupons of 4750 steel (bottom left) after soaking in a 10 percent solution of Intex 8125 at 155 F for 16 hours. The same figure shows chromium steel (bottom right) after soaking in a 20 percent solution of Intex 8125 at 120 F for 16 hours. The top row shows the alloys in the untested condition. The weight loss data corraborated these observations as illustrated in Figure 6, which shows the large weight loss of chromium steel in Intex 8125 and 8284, and deionized water.

Aluminum Alloys

As a group, these alloys suffered the greatest amount of degradation in the various cleaners. Anodized aluminum AA 2017 was not compatible in Versa Clean*, EZE 244, Brulin 815 GD, or Intex 8284 for the 5-minute sonication test. Figure 7 is a photograph showing the severe corrosion damage suffered by anodized aluminum (bottom row) in the 16-hour soak test. The left-most coupons of the top and bottom rows show the appearance of untested AA 6061 and anodized AA 2017,

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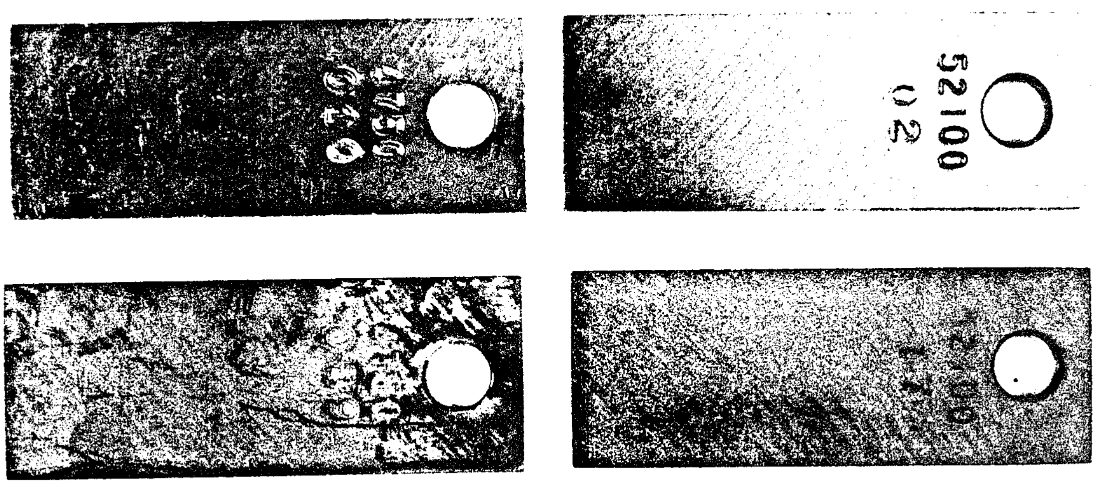
* Compatible in Versa Clean only at the lower concentrations ≤ two vol. percent or lower.



1.35X K-10636-5

4750 Steel **Chromium Steel**

Figure 5. Photograph of alloys 4750 steel (left) and chromium steel (right). Top row shows coupons in untested condition. Bottom row (left) shows 4750 steel after soaking at 155 F for 16 hours in 10 vol. percent solution of Intex 8125. Bottom row (right) shows condition of chromium steel after soaking at 120 F for 16 hours in 20 vol. percent solution of Intex 8125.

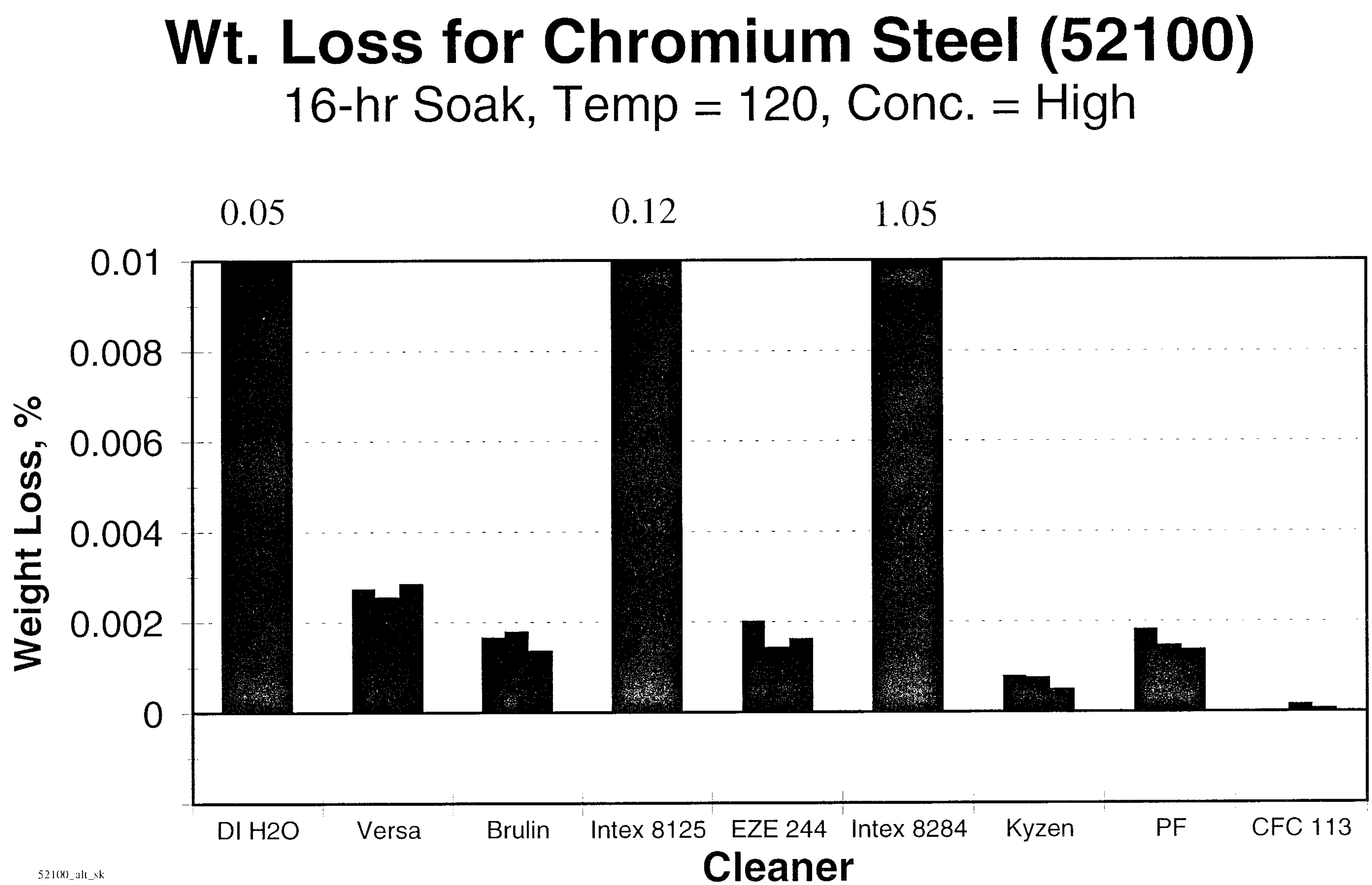
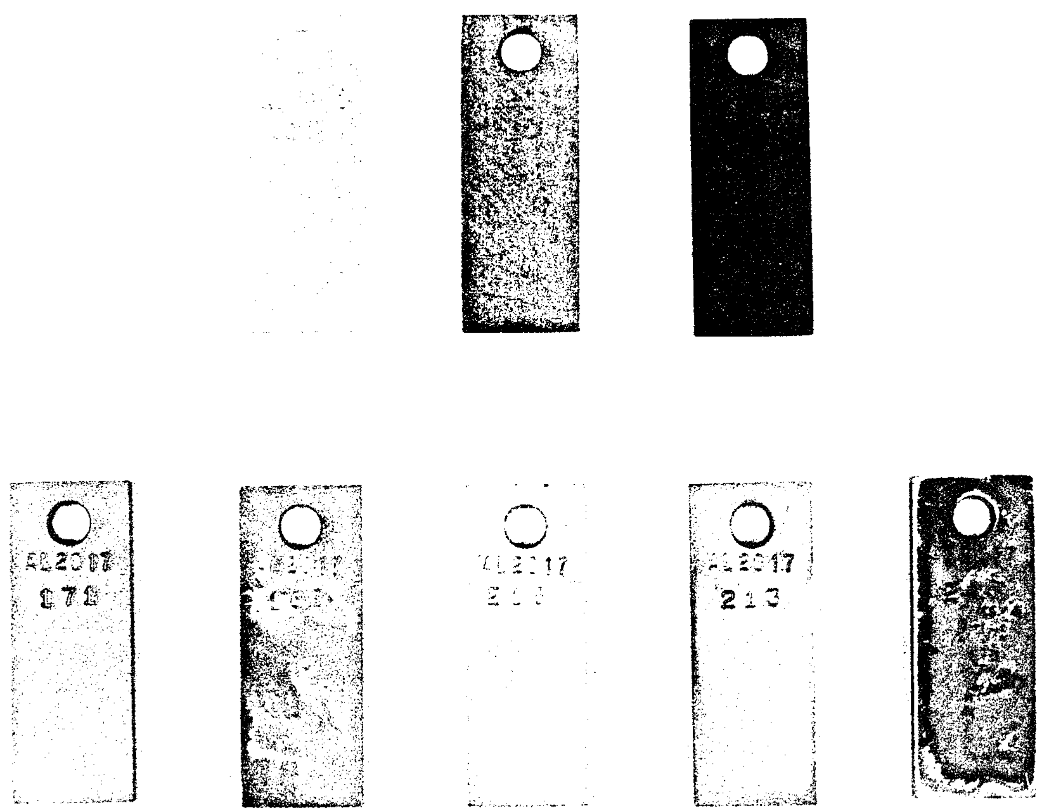


Figure 6. Bar chart of chromium steel's weight loss after the 16-hour soak test

Baseline | EZE 244 at 120 F | Versa Clean (6.3%) at 120 F



Baseline | EZE 244 at 120 F | Intex 8284(5%) at 120 F | Intex 8125(20%) at 120 F | Intex 8284(15%) at 155 F

0.8X

K-10636-1

Figure 7. Photograph of aluminum 6061 coupons (top row) and anodized aluminum 2017 (bottom row) coupons showing the range of corrosion behavior exhibited by the coupons after 16 hours of soaking in various cleaners (see text).

respectively, for comparison. Soaking in Versa Clean, EZE 244, Intex 8125 and Intex 8284 removed most of the anodized layer.

Similarly, Alloys AA2017 and AA6061 were not compatible with Versa Clean (except at a concentration of two percent or lower) or EZE 244 in the sonication test, but they were compatible with the other cleaners in the sonication test. The mode of attack was primarily pitting corrosion followed by general corrosion. In the cases of the most severe degradation, general corrosion was predominant. Alloys AA2017 and AA6061 exhibited similar behavior in the soak tests. Aluminum 6061 turned black when tested in Versa Clean (see Figure 7).

Beryllium

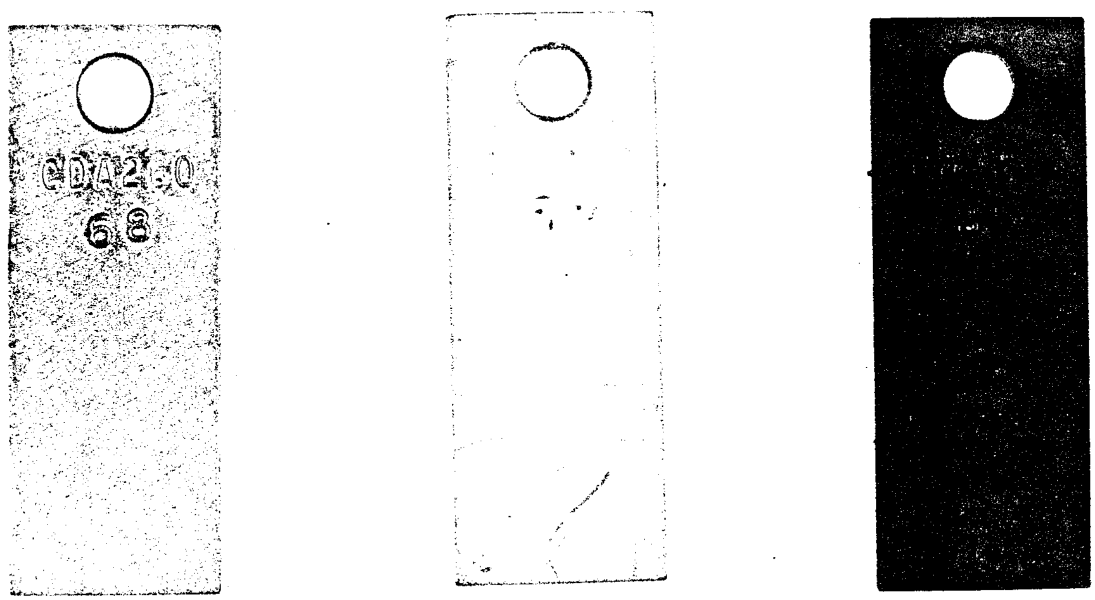
Beryllium was compatible with all the cleaners during the 5-minute sonication test. Beryllium was also compatible with all the cleaners during the 16-hour soak test with the exception of Intex 8284 where it exhibited signs of localized attack (see Appendix I). This attack was general corrosion that occurred preferentially near rougher areas on the surface.

Copper-Base Alloys

The copper-base alloys, namely beryllium copper, cartridge brass, and chromium copper behaved similarly in the various cleaners in both the sonication and soaking tests. In the sonication test, cartridge brass was incompatible with Versa Clean at the higher concentration (6.3 vol. percent), but it was compatible at the lower concentration (2 vol. percent).

In general, the same cleaners that caused excessive degradation in the aluminum alloys during the soaking tests also caused excessive corrosion in the copper-base alloys. In addition, Kyzen Aquanox X2031 caused excessive degradation in cartridge brass and chromium copper.

Cartridge brass had perhaps the most striking response to the cleaners during the soak tests. After soaking in Kyzen Aquanox X2031, cartridge brass developed a white, soft deposit that became visible on its surface immediately after it had been dried (see Figure 8). This film was analyzed by infrared spectroscopy to be a mixture of aromatic and aliphatic hydrocarbons, which is consistent with the components of Kyzen. A similar film formed on chromium copper after the 16-hour soak test, but to a much lesser extent. Cartridge brass also developed a thin, black, tenacious film on its surface



1.5X

K-10636-4

Figure 8. Photograph of cartridge brass coupons, untested (left), after 16-hour soak at 120 F in Kyzen X2031 (middle), and 16-hour soak at 155 F in Brulin 815 GD (9.1 vol. percent).

after soaking in Brulin 815 GD. The primary mode of attack on all the copper-base alloys was general corrosion.

Gold-Plated Brass

Gold-plated brass was found to be compatible with all cleaners at both temperatures and both cleaning methods.

HyMu77

By virtue of its high nickel content, this alloy was fairly corrosion resistant. It was completely compatible with all the cleaners in the sonication test but was not compatible with Intex 8284 at any soak time. This is likely due to Intex being an acid-type cleaner, which is highly aggressive to aluminum, copper, and nickel-iron alloys. The mode of degradation was general corrosion.

Solder

This solder alloy, 60Sn-40Pb, was not tested in the 5-minute sonication cleaning method. However, because its surface was so soft, it would likely have less cavitation damage from the sonication action compared to harder metals.

The solder coupons were soak tested at only one hour and ten minutes. Solder was not compatible with Intex 8125 for either soaking period. It was compatible with Versa Clean, EZE 244, Brulin GD 815, and Intex 8284 for up to ten minutes of soaking. The mode of attack on the solder by Intex 8284 was general corrosion. It is likely that solder would have been compatible with PF Degreaser, CFC 113, deionized water, and Kyzen for a 16-hour soak.

Types 304 and 316 Stainless Steel, and Inconel 600

The stainless steels tested and Inconel 600 were compatible with all cleaners at both temperatures and both cleaning methods. These alloys are known to be corrosion resistant to a wide variety of aqueous solutions, particularly those without chlorides. Other alloys that would have equal or better corrosion resistance than these alloys include all Hastelloys, all Inconels, all Incoloys, duplex stainless steels, superferritic stainless steels, and highly alloyed austenitic stainless steels.

Chemical Analysis of Cleaner Solutions

A negative weight loss indicated that the coupon gained weight after it was cleaned. In most cases the weight gain was associated with an adherent visible hydroxide, in the case of aluminum, or another type of reaction product that leaves a visible film on the coupon's surface, such as Kyzen X2031 on cartridge brass. If the metal did lose weight, then an analysis of the cleaner solution should reveal the dissolved metal in solution.

The results of the ICP analysis on various cleaner solutions indicated excellent agreement between the weight loss data and the photomicrographs. For example, triplicate coupons of 4750 steel soaked in Intex 8284 resulted in a total measured weight loss corresponding to 17 μg/mL (ppm) in solution. A chemical analysis of the solution indicated the presence of 10 μg/mL of iron in solution, the major constituent of 4750 steel. A similar agreement was found in the case of beryllium tested in Intex 8284. This technique also confirmed that weight gain on aluminum coupons soaked in deionized water does not result in the aluminum dissolving in solution. The weight gain was likely due to the formation of a thin transparent aluminum hydroxide film that adhered to the surface. The complete results of the ICP analyses are shown in Appendix L.

Summary of Cleaner Compatibility

The following paragraphs summarize the extent of compatibility of each cleaner.

DI H_2O: Deionized water at 18 MΩ·cm resistivity was compatible with all the metals in the sonication test. Chromium steel was the least compatible metal tested for soaking in deionized water. Two aluminum alloys were compatible only up to 60 minutes of soaking.

Versa Clean: When used at the two percent concentration level, Versa Clean is compatible with all the metals tested in the sonication cleaning method. In the soaking tests, it was incompatible with AA6061 and compatible with the other aluminum alloys only at the shorter soak times.

Brulin 815 GD: This cleaner was compatible with all the alloys in the sonication test except anodized aluminum. Brulin 815 GD was compatible with the copper-base alloys and solder only at the shorter soak times.

Intex 8125: Intex 8125 was compatible with all the metals during the sonication test but was not compatible with solder in the soak test, and compatible with the aluminum alloys only for the shorter soak times. Chromium steel and 4750 steel were also compatible only at the shorter soak times.

EZE 240: EZE 240 was tested only with AA2017 and was compatible with the sonication test but compatible only during the soaking test when used at the higher temperature of 155 F.

EZE 244: This was one of the more aggressive cleaners used. None of the aluminum alloys was compatible with this cleaner in the sonication test or the soaking test except the anodized coupons tested at the higher temperature of 155 F. The copper base alloys and the solder could be used in EZE 244 only at the shorter soak times.

Intex 8284: This cleaner was the most aggressive of the cleaners tested in this program. It was not compatible with anodized aluminum in the sonication test. Only gold-plated brass, Inconel 600, and the two stainless steel alloys were compatible with Intex 8284 at the 16-hour soak time. All the other alloys were either incompatible or compatible at the shorter soak times.

Kyzen Aquanox X2031: All the metals tested were compatible with this cleaner in the sonication test. Cartridge brass was the only incompatible alloy in the soak tests because the cleaner reacted with the metal and left a soft, white film on its surface.

PF Degreaser: Compatible with all the metals for both cleaning methods at the maximum cleaning times. Tested at 120 F only because of flashpoint is 140 F.

CFC 113: This cleaner was the control against which all the other cleaners were compared. It was compatible with all the metals for both cleaning methods at the maximum cleaning times. Tested at 115 F because boiling point is 118 F.

Conclusion and Recommendations

The conclusion of this study is that although alternative aqueous cleaners can be used to successfully replace the traditional CFC cleaners, no single replacement cleaner can be used for all the metals that AGMC cleans during their repair and servicing operations. Cleaners and cleaning methods must be matched to specific metals according to the compatibility tables (Tables 5 and 6) generated in this study to ensure that the parts to be cleaned do not suffer any deleterious surface effects.

The cleaning effectiveness of the aqueous cleaners was not examined in this study. The compatibility tables only address whether degradation of the metals occur when cleaned. These tables are strictly valid only for the parameters used in this study, namely for temperatures between 120 F and 155 F, five-minute sonication times, and soaking times less than or equal to 16 hours. One can safely extrapolate the data to less severe cleaning conditions such as shorter soak times or shorter sonication times, but extrapolating to higher or lower temperatures than those tested or higher cleaner concentrations is unwise.

Kyzen X2031, Intex 8125, and deionized water were the aqueous cleaners that were compatible with all the metals during the five-minute sonication. Aqueous cleaners Brulin 815 GD and Intex 8284 were compatible with all the metals during sonication except anodized AA 2017. Brulin 815 GD and Kyzen X2031 were compatible with all the metals tested except the copper-base alloys and solder for all soak times tested.

Appendix A

Elemental Composition of Tested Metals

Table A-1. Composition of Alloys[a]

Alloy Name[b]	Common Name	UNS Designation	Elemental Composition, Weight Percent														Mill
			Al	C	Cr	Cu	Fe	Mn	Mo	Ni	P	S	Si	Ti	Be	Other	
4750	4750 Steel	not available		0.002	0.06	0.016	Bal.	0.46		48.11	0.009	0.0008	0.36			0.005 Co	Allegheny Ludlum
AA2017-T0	Aluminum 2017	A92017	Bal.		0.10	3.5-4.5	0.70	0.4-1.0					0.20-0.80	0.15			Earl M. Jorgensen
AA6061-T4	Aluminum 6061	A96061	Bal.		0.04-0.35	0.15-0.40	0.70*	0.15*					0.40-0.80	0.15*		0.80 Mg, 0.25 Zn	Alcoa Aluminum
Beryllium	Beryllium Grade A	not available	0.016*		0.15*		0.18*						0.08*		98.0	2.0 BeO, 0.08 Mg	not available
CDA172	Beryllium Copper	C17200	0.07		0.006	Bal.	0.06			0.05			0.09		1.83	0.21Co, 0.01 Zn	Brush Wellman
CDA260	Cartridge Brass	C26000				68.5-71.5	0.05									0.07 Pb Max., Bal. Zn	Tull
CDA182	Chromium Copper	C18200			0.6-1.2	99.5	0.1						0.1			0.05 Pb	Copper & Brass Sales
C52100	Chromium Steel	G52986		1.03	1.37	0.07		0.39	0.03	0.08	0.008	0.001	0.26				Republic Engineered
HyMu77	HyMu77	not available	0.006	0.009	2.31	4.71	Bal.	0.55	0.04	76.78	0.003	0.002	0.26			0.26 Co	Carpenter
I600	Inconel 600	N06600		0.02	14.76	0.04	6.43	0.21		78.35		<0.001	0.19				INCO Alloys
Solder	60Sn/40Pb	not available	0.001			0.005	0.001			0.005	0.006	0.001				59.6 Sn, 0.18 Sb, Bal. Pb	Federated-Fry Metals
Type 304	Type 304 Stainless Steel	S30400		0.057	18.23	0.31	Bal.	1.40	0.22	8.19	0.026	0.002	0.49			0.16 Co, 0.022 N	Ryerson & Son
Type 316	Type 316 Stainless Steel	S31600		0.041	16.70	0.32	Bal.	1.70	2.06	10.11	0.03	0.009	0.56			0.12 Co, 0.031 N	Ryerson & Son

(a) All elemental concentrations, except beryllium's, were supplied by mill vendor; beryllium composition is based on the requirements of Autonetics Corporation.
(b) AA = Aluminum Association, CDA = Copper Development Association
* = maximum concentration

Appendix B

Description of the Four Major Experiments

Experiment No. 1. Characterization of Degradation

The first experiment was directed toward characterizing degradation following exposure of a single metal to aqueous cleaning. For this experiment, Aluminum 2107, one of the more susceptible materials to general and localized corrosion attack of all the alloys listed in Appendix A, was selected for testing. A screening design that is a one-half fraction of the full factorial* on nine cleaners, two cleaning methods, two temperatures, and two concentrations was selected. The design is shown in Table B-1. Thus, in 32 trials (run in triplicate) the design would uncover the main effects of the three variables (method, temperature, and concentration) as well as their first-order interactions (i.e., method-temperature, method-concentration, and temperature-concentration interactions) for Aluminum 2017 and each cleaner. The three-way interaction between method, temperature, and concentration would not be discernable from this set of four trials for each detergent.

* The full factorial in this case is 64 trials, not 9x2x2x2=72 trials because of restrictions on concentration and temperature variations for certain cleaners.

Table B-1. Thirty-two-trial screening design for Experiment No. 1

X_1 Metal	X_2 Detergent/Cleaner	X_3 Method[(a)]	X_4 Temperature[(b)] (F)	X_5 Concentration[(c)] (vol. %)
AA 2017	DI H_20	U	120	neat
AA 2017	DI H_20	U	155	neat
AA 2017	DI H_20	S	120	neat
AA 2017	DI H_20	S	155	neat
AA 2017	Versa Clean	U	120	9.1
AA 2017	Versa Clean	U	155	9.1
AA 2017	Versa Clean	S	120	1.6
AA 2017	Versa Clean	S	155	9.6
AA 2017	Brulin	U	120	4.8
AA 2017	Brulin	U	155	4.8
AA 2017	Brulin	S	120	9.1
AA 2017	Brulin	S	155	4.8
AA 2017	Intex 8125	U	120	10
AA 2017	Intex 8125	U	155	10
AA 2017	Intex 8125	S	120	10
AA 2017	Intex 8125	S	155	20
AA 2017	EZE 240	U	120	10
AA 2017	EZE 240	U	155	10
AA 2017	EZE 240	S	120	2
AA 2017	EZE 240	S	155	10
AA 2017	Intex 8284	U	120	5
AA 2017	Intex 8284	U	155	5
AA 2017	Intex 8284	S	120	15
AA 2017	Intex 8284	S	155	5
AA 2017	Kyzen	U	120	neat
AA 2017	Kyzen	U	155	neat
AA 2017	Kyzen	S	120	neat
AA 2017	Kyzen	S	155	neat
AA 2017	PF Degreaser	U	120	neat
AA 2017	PF Degreaser	S	120	neat
AA 2017	CFC-113	U	120	neat
AA 2017	CFC-113	S	120	neat

(a) U = 5-minute sonication, S = 16-hour soak.
(b) PF Degreaser and CFC 113 could only be tested at the lower temperature.
(c) PF Degreaser, Kyzen, DI H20, and CFC-113 are used only neat.

The data were analyzed for significant effects using the following model shown in Equation (B-1) for each cleaner and each response:

$$Y=C+B_1X_3+B_2X_4+B_3X_5+B_4X_3X_4+B_5X_3X_5+B_6X_4X_5 \quad \textbf{(B-1)}$$

Where

Y = a response

B_j, C = constants determined by multiple regression analysis

X_i = variables defined in Table B-1.

The results were analyzed using multiple regression analysis to determine the coefficients in the foregoing model that provided the best least-squares fit to the data obtained. For each cleaner, the set of conditions causing the greatest degradation of the metal coupons was determined.

Experiment No. 2. Weight Loss as a Function of Cleaner Concentration

The purpose of Experiment No. 2 was to determine the effect of concentration. This was particularly important if one wanted to interpolate the effect of degradation as a function of concentration. Degradation as a function of cleaner concentration could be constant, could increase or decrease monotonically, or have either a local minimum or maximum value. This experiment was designed with three levels of concentration and was used to isolate the nonlinear behavior or to confirm its linearity.

The design for Experiment No. 2 is shown in Table B-2. It consisted of 16 trials (run in triplicate) using non-anodized Aluminum 2017, as in Experiment No. 1, and in the cleaner that showed either the most degradation or greatest difference in degradation between minimum and maximum concentrations (in this case Versa Clean). If degradation occurred, analysis of the data would illustrate the effect of concentration. The assumed mathematical model is shown in Equation (B-2).

$$Y = C + B_1X_3 + B_2X_4 + B_3X_5 + B_4X_3X_4 + B_5X_3X_5 + B_6X_4X_5 + B_7X_5^2 + B_8X_3X_4X_5 \quad \textbf{(B-2)}$$

where X_i are variables defined in Table B-2.

Table B-2. Full factorial design for Experiment No. 2 using AA 2017 in Versa Clean

X_3 Cleaning Method	X_4 Temperature (F)	X_5 Concentration (Vol. %)
Sonication	120	1.6
Sonication	120	3.2
Sonication	120	6.3
Sonication	120	9.1
Sonication	155	1.6
Sonication	155	3.2
Sonication	155	6.3
Sonication	155	9.1
Soaking	120	1.6
Soaking	120	3.2
Soaking	120	6.3
Soaking	120	9.1
Soaking	155	1.6
Soaking	155	3.2
Soaking	155	6.3
Soaking	155	9.1

If the effect of concentration was found to be essentially linear, then two levels (the originally selected low and high levels) of concentration would be sufficient in subsequent experiments to elucidate the effect of concentration throughout the rest of the study, and information content would not be compromised by this decision. Though the concentration tests were conducted only on Versa Clean, the results were assumed to apply to the other aqueous cleaners used at various concentrations, namely Brulin 815 GD, Intex 8125, and Intex 8284.

The electrochemical corrosion processes of these aqueous cleaners on metals will be similar to each other even though these cleaners differ from one another chemically.

On the other hand, if the effect was found to be nonlinear, it would have been be necessary to judge how important this effect was. Because the goal was to identify the potential for degradation, selecting worst-case conditions to evaluate it was reasonable so long as these were feasible representations of operational scenarios. The recommendation would then be to select, for the remainder of the study, the manufacturer's recommended concentration and the worst-condition concentration to coincide with the best and worst cases.

Experiment No. 3. Evaluation of Four Common Metals

Experiment No. 3 was similar to Experiment No. 1 in that it used a screening design to develop a model of the form shown in Equation 1 for four common metals and the nine cleaners under study. The design was the same as that for Experiment No. 1 for each of the metals except that the concentration values were adjusted to extract additional statistical information (see Table B-3). Thus, it consisted of 128 trials run in triplicate (except beryllium which was run in duplicate). The choices for these four metals were beryllium, cartridge brass, 50% Ni-Fe alloy (4750 steel), and anodized Aluminum 2017. These metals were chosen because of their susceptibility to corrosion and because they are frequently cleaned at AGMC.

Multiple-regression analysis of the data indicated significant effects on degradation of the metals. A comparison of these four metals with Aluminum 2017, which is also commonly used, was made to validate the assumption that worst-case conditions are the same for all metals. The initial assumption was that the results would be similar for all five metals evaluated up to this point. This assumption was validated by the experimental results. Based upon these findings, a decision was made for each cleaner concerning the combination of method, temperature, and concentration that is most likely to cause degradation. This combination was used in Experiment No. 4 on the remaining metals, which are more expensive or less commonly used.

Table B-3. Thirty-two-trial screening design for Experiment No. 3

X_1 Metal	X_2 Detergent/Cleaner	X_3 Method[(a)]	X_4 Temperature[(b)] (F)	X_5 Concentration[(c)] (vol. %)
Anodized AA 2017, beryllium, cartridge brass, and 4750 steel were each tested using this design.	DI H_20	U	120	neat
	DI H_20	U	155	neat
	DI H_20	S	120	neat
	DI H_20	S	155	neat
	Versa Clean	U	120	2.0
	Versa Clean	U	155	6.3
	Versa Clean	S	120	2.0
	Versa Clean	S	155	6.3
	Brulin	U	120	4.8
	Brulin	U	155	9.1
	Brulin	S	120	4.8
	Brulin	S	155	9.1
	Intex 8125	U	120	5
	Intex 8125	U	155	10
	Intex 8125	S	120	20
	Intex 8125	S	155	10
	EZE 244	U	120	neat
	EZE 244	U	155	neat
	EZE 244	S	120	neat
	EZE 244	S	155	neat
	Intex 8284	U	120	5
	Intex 8284	U	155	5
	Intex 8284	S	120	5
	Intex 8284	S	155	15
	Kyzen	U	120	neat
	Kyzen	U	155	neat
	Kyzen	S	120	neat
	Kyzen	S	155	neat
	PF Degreaser	U	120	neat
	PF Degreaser	S	120	neat
	CFC-113	U	120	neat
	CFC-113	S	120	neat

(a) U = 5-minute sonication, S = 16-hour soak.

(b) PF Degreaser and CFC-113 could only be tested at the lower temperature.

(c) PF Degreaser, Kyzen, DI H20, and CFC-113 are used only neat.

Experiment No. 4. Evaluation of Remaining Metals in the Hostile Conditions

Each of the remaining ten metals was run in each of the nine cleaners to determine its potential for degradation in the presence of each of the cleaners evaluated. The results of this experiment were used to determine which cleaners are compatible with all the tested metals.

This experiment consisted of 162 trials. The form of the design is shown in Table B-4 as an eighteen-trial screening design that was run for each of the ten metals (solder was run in soaking only). The specific concentration and temperature used for each of the ten metals and nine cleaners were determined based on the results of the first three experiments. A statistical analysis was conducted (see Appendix F) to determine which temperature and concentration would result in the most hostile testing environment for the remaining metals.

Table B-4. Eighteen-trial screening design for Experiment No. 4

X_1 Metal	X_2 Detergent/Cleaner	X_3 Method[(a)]	X_4 Temperature (F)	X_5 Concentration[(b)] (vol. %)
AA 6061, beryllium copper, chromium copper, chromium steel, gold-plated brass, HyMu77, Inconel 600, and Types 304 and 316 stainless steels were each tested using this design.	DI H_20	U	120	neat
	DI H_20	S	120	neat
	Versa Clean	U	120	6.3
	Versa Clean	S	120	6.3
	Brulin	U	120	9.1
	Brulin	S	120	9.1
	Intex 8125	U	120	10
	Intex 8125	S	120	20
	EZE 244	U	120	neat
	EZE 244	S	120	neat
	Intex 8284	U	120	15
	Intex 8284	S	120	15
	Kyzen	U	120	neat
	Kyzen	S	120	neat
	PF Degreaser	U	120	neat
	PF Degreaser	S	120	neat
	CFC-113	U	120	neat
	CFC-113	S	120	neat

(a) U = 5-minute sonication, S = 16-hour soak.

(b) DI H_2O, Kyzen Aquanox X2031, PF Degreaser, and CFC-113 are used only neat.

Appendix C

Metal Coupon Preparation and Testing Procedure

Metal Coupon Preparation

Geometry

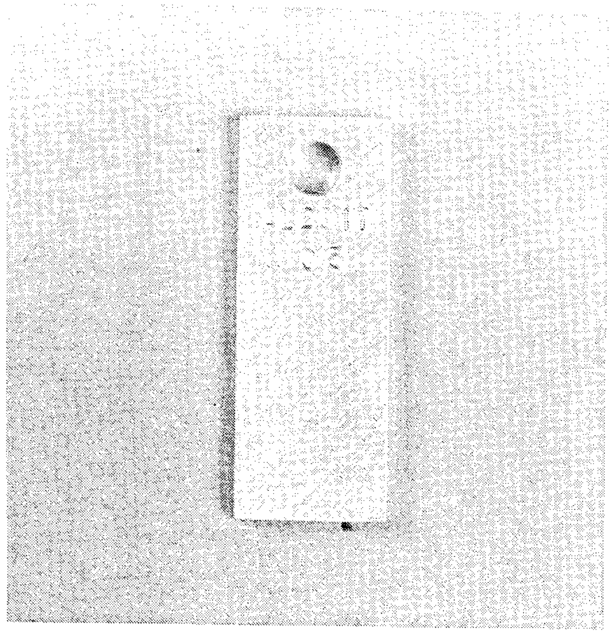
Flat Coupons. All the metal coupons, except beryllium, were supplied and machined by the same vendor (Metal Samples Corporation of Munford, Alabama). Figure C-1 is a photograph showing the geometry of the coupons from Metal Samples. All these coupons had dimensions of 2-inches (50.4 mm) long, 0.75-inch (19.1 mm) wide. The thicknesses for all of the Metal Sample coupons were 0.125-inch (3.2 mm) except for HyMu77, which was available only in 0.0625-inch (1.6 mm) thickness. All the flat coupons had a 0.25-inch (6.4 mm) diameter hole machined and centered 0.25-inch from one end to facilitate hanging them in their test solutions. An identification number was stamped in each coupon with a tungsten carbide die.

Beryllium Specimens. All the beryllium specimens were supplied by AGMC. These specimens consisted of halves of threaded, machined, circular parts (see Figure C-1) that originally formed the PIGA main housing of a missle guidance system.

Surface Finish

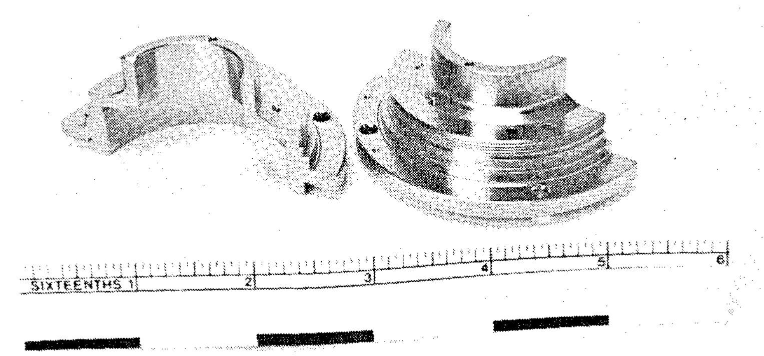
The surfaces of the flat coupons were ground to a finish of 32 microinches rms, the value specified by the parts list supplied by AGMC. This finish was accomplished by using a double disk grinding method on the coupons. The surface finish appearance varied slightly from metal to metal depending on the metal's hardness. The surface finishes for the flat coupons prior to testing are shown in Appendix J. The beryllium specimens were not ground by the double disk method and had a somewhat smoother appearance than the flat coupons. Scotch Brite scouring pad were used to polish the solder coupons because the solder was too soft to grind by conventional methods.

Anodizing and Gold-Plating. Two metals were given additional surface treatments for some of the tests, namely anodizing for AA2017 and gold-plating for cartridge brass. The anodizing was done according to Mil-A-8625 (Type II) by Lancaster Electroplating. The anodized layer was approximately 0.3 mil (0.0003 inch) thick and dyed gold in color. The gold-plating was done according to Mil-G-45204 (Type II, Class 1) by AMAX Plating, Inc. The nominal gold-plate thickness was 0.08 mil (0.00008 inch).



1X K-10422-6

(a)



0.6X K-10636-7

(b)

Figure C-1. Photographs showing geometry of flat coupon (a) and beryllium coupons (b) made from the PIGA main housing.

Chemical Composition

The chemical compositions of all the coupons (except beryllium) were supplied by the mills that made the metals. The composition of the beryllium coupons was listed in documentation supplied by AGMC. Appendix A lists the compositions of the coupons.

Cleaning Protocols

Precleaning

All the coupons were handled with latex rubber gloves to avoid the possibility of contamination by fingerprints. The flat coupons were received individually wrapped with paper impregnated with a corrosion inhibitor to prevent any corrosion of the coupons during shipping. All the specimens were precleaned in the same manner prior to subjecting them to either the soaking or sonication tests. All the coupons were mounted on Teflon holders during their precleaning, cleaning, and drying procedures. The precleaning procedure was as follows:

1. Coupons sonicated in a Branson ultrasonic cleaner[*] containing room temperature CFC-113 for one minute.

2. Coupons removed from Branson tank and blow-dried with filtered, compressed air[**].

3. Dried coupons placed in a vacuum oven (30 mm Hg) for 15 minutes at 155 F.

4. Vacuum pump and oven heater turned off after 15 minutes and the oven backfilled with the filtered compressed air. This allowed the coupons to cool within a reasonable time of several hours. The coupons were removed from the oven when they reached a temperature of 80 F.

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[*] Branson Model 3200

[**] Shop air was filtered to remove water, oil down to 0.003 ppm by wt., and particulates above 0.01 microns.

5. Coupons were removed from the vacuum oven and placed in a desiccator for at least one hour prior to initial weighing.

6. Coupons were removed from their desiccator and weighed with an analytical balance* to a precison of 0.01 mg.

The next several sections detail the cleaning test procedure each coupon underwent after its initial weighing.

Soak Cleaning Test Method

The soak cleaning consisted of immersing a set of triplicate coupons in their cleaning solutions according to the following procedures:

1. The cleaning solutions were prepared no more than 24 hours prior to use according to the manufacturers' specifications and then heated to temperatures specified in the design of the experiment (120 F or 155 F). The nominal cleaning solution concentration corresponded to the manufacturer's specifications. Cleaning solution concentrations used in the tests along with their measured pH are shown in Table C-1.

2. Two-liter Pyrex beakers were filled with 1.8 liters of the cleaning solution and heated to its test temperature using a stirring hot plate. When the cleaning solution reached its test temperature (120F or 155F), the triplicate group of a test alloy were completely immersed in the solution. The coupons were suspended in the solution by teflon racks (see Figure C-2) which prevented the coupons from coming in contact with each other or the sides of the beaker. The immersion time ranged from ten (10) minutes to sixteen (16) hours. The Pyrex beakers were covered with a watch glass during the soaking period to minimize the evaporation of the solution.

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* Mettler Model AT250

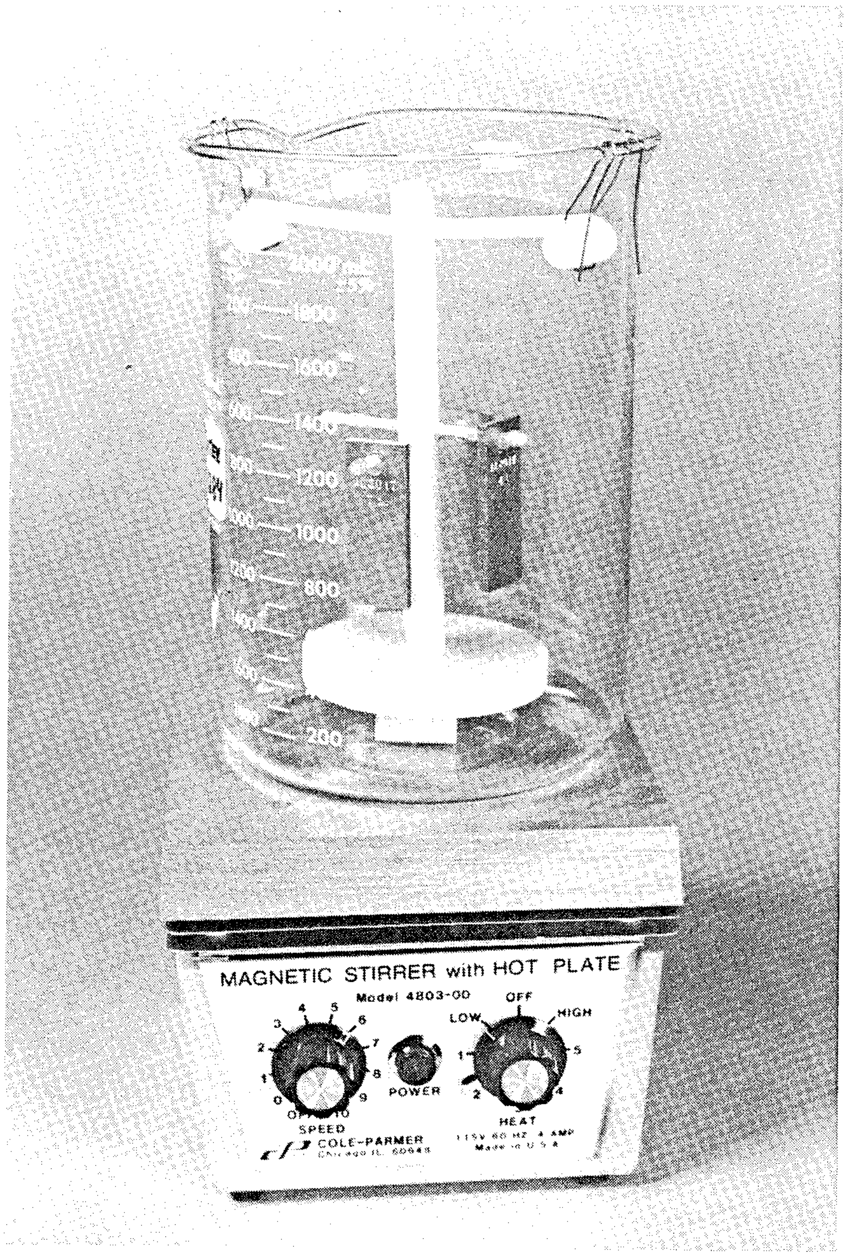
Table C-1. Concentrations and pH values of cleaners used in the study

Detergent/Cleaner Name	Manufacturers' Recommended Cleaner Conc. Ratio (vol. %)	Actual Conc. Tested (vol. %)	pH at 120 F
Deionized water[a]	not applicable	not applicable	6.0
Versa-Clean	1:30 (3.2)	1.6	8.9
		3.2	9.4
		6.3	9.4
		9.1[b]	9.1
Brulin 815 GD	1:20 (4.8)	4.8	10.2
		9.1	10.2
Intex 8125	1:20 (4.8)[c] 1:10 (9.1)	4.8	7.8
		10	7.6
		20	7.5
EZE 240	1:40 (2.4)	2	8.7
		10	8.7
EZE 244	Neat	Neat	10.8
Intex 8284	1:20 (4.8)	5	4.0
		15	3.8
Kyzen Aquanox X2031	Neat	Neat	9.5
PF Degreaser	Neat	Neat	not applicable
CFC-113	Neat	Neat	not applicable

(a) Type E-2 Electronic grade water, resistivity = 17.5 MΩ·cm .

(b) Only AA 2017 was tested at 1.6, 3.2, 6.3 and 9.1 vol. percent. All other alloys were tested at either 2.0 or 6.3 vol. percent in Versa Clean.

(c) 1:20 for sonication, and 1:10 for soaking.



0.4X K-10466-5

Figure C-2. Photograph showing soaking test arrangement of coupons on Teflon rack in Pyrex beaker (solution not present).

3. After the immersion period, the coupons were removed from the solutions and rinsed with heated (155 F), flowing deionized water* for 5 minutes (see Figure C-3 for schematic of deionization system). After rinsing, the coupons underwent the drying procedure.

Soak Periods. An initial soaking period of 16 hours was chosen to ensure that any deleterious effects of the cleaners on the metals would become evident and to simulate the condition of a user inadvertently leaving components in the cleaner overnight. Metals not exhibiting degradation after 16 hours of soaking would certainly be compatible when exposed to the cleaner for shorter times. In cases where degradation occurred after 16 hours of exposure, new coupons of the metal were tested for a period of one hour. One hour is usually the maximum time users would soak components in cleaners. If the metal continued to exhibit degradation after only a one-hour soak, then a ten-minute soaking time would be used to test new coupons of the metal in question. Metals that still showed degradation after ten minutes of soaking were judged to be unacceptable for any soaking period at the test temperature (and concentration, if applicable).

Sonication Cleaning Test Method

The sonication cleaning method consisted of exposing a set of triplicate coupons to their cleaning solutions according to the following procedures:

1. The cleaning solutions were prepared in the same manner as in the soaking procedure except the solution quantity was at least 4.4 gallons (16.6 l), the minimum volume required for the Sonic Systems sonication tank. The holding tank temperature was adjusted to the temperature specified in the experimental design: i.e., 120 F or 155 F.

2. A triplicate set of coupons of a test alloy was completely immersed in the sonication cleaning tank for a period of 5 minutes. The suspended coupons were not allowed to contact each other or the walls of the sonication tank.

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* Nominal resistivity of the deionized water was 18 MΩ·cm.

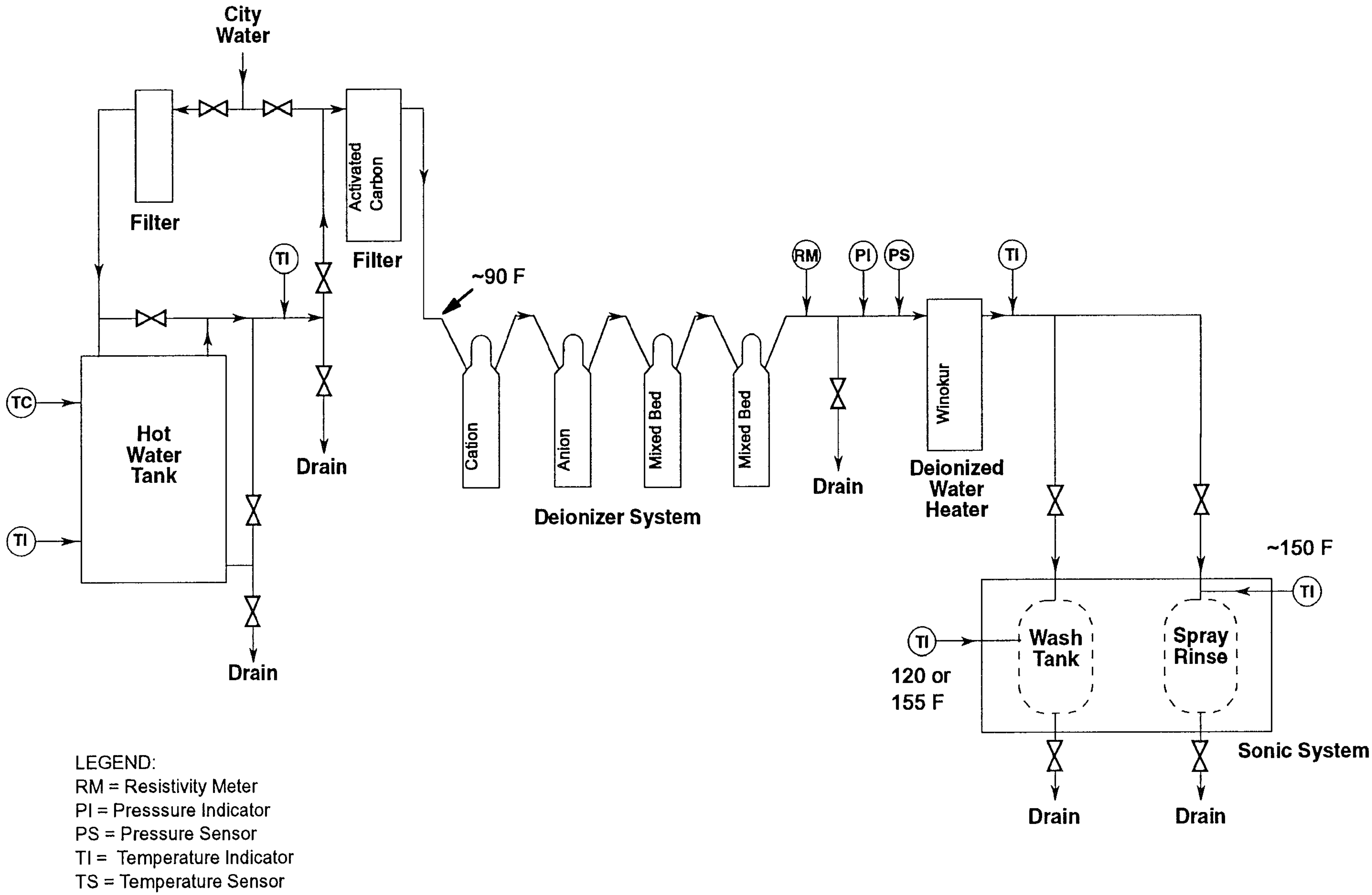

Figure C-3. Schematic of Deionized Water System

3. After five minutes of sonication, the coupons were transferred to the rinse tank and rinsed in the same manner described in paragraph 3 under the **Soak Cleaning Test Method** section. After rinsing, the coupons underwent the drying procedure.

Sonication Period. A time of five minutes was used for all the sonication tests. The sonication time used in most cleaning procedures is anywhere from several seconds to several minutes. Five minutes was chosen to simulate the extreme end of sonciation exposure periods.

Sonication Power and Frequency. A Sonic Systems, Inc. model 3215IS cleaning station was used for the 5-minute sonication and high temperature deionized water rinsing of the coupons. The actual sonication power that reached an immersed coupon was not measured in this study. The ultrasonic generator, Sonic Systems model 4006, was rated at 600 W at a nominal frequency of 40kHz. The variable power rheostat on the Sonic Systems unit was used at 100 percent full power during the tests. The power density was estimated at approximately 100 W per gallon of solution based on a solution volume of five gallons and sonication power of 500 W.

Coupon Drying Procedure

The tested coupons from both cleaning methods were dried according to the following procedure:

1. Coupons were blow dried with filtered high-purity compressed air. The compressed air was obtained in standard high pressure gas cylinders from Matheson Gas Products. The gas pressure was regulated between 50 and 80 psi.

2. The blown-dry coupons were then placed in a vacuum oven preheated to 155 F. The coupons were held in the heated vacuum oven for a minimum of 15 minutes after the vacuum gage reading fell below 30 inches of Hg. The procedure for removing the vacuum-dried coupons was in the same manner as described in the **Precleaning** section.

Final Weighing

The coupons were weighed again to a precision of 0.01 mg after they have been subjected to their drying procedure. Differences measured between the initial and final weights of each tested and control coupons were used in assessing whether any corrosion occurred in the tested coupons during their cleaning process.

Appendix D

Statistical Analysis of Aluminum Degradation
(Experiment No. 1)

Tabulation of Weight Loss by Detergent/Cleaner

ROWS: Det

	WtChg N	WtChg MEAN	WtChg STD DEV
1	6	0.18124	0.19389
2	3	-0.00008	0.00018
3	6	0.01836	0.01354
4	6	-0.00026	0.00189
5	6	0.17529	0.09814
6	6	0.06039	0.02063
7	6	0.00383	0.00396
8	6	-0.03239	0.02663
9	3	0.00107	0.00109
ALL	48	0.05087	0.10622

Tabulation of Weight Loss by Detergent/Cleaner (Rows) and Temperature (Columns)

ROWS: Det COLUMNS: Temp

	115	120	155	ALL
1	0	3	3	6
	--	0.00425	0.35823	0.18124
	--	0.00261	0.00257	0.19389
2	0	3	0	3
	--	-0.00008	--	-0.00008
	--	0.00018	--	0.00018
3	0	3	3	6
	--	0.02822	0.00850	0.01836
	--	0.01200	0.00478	0.01354
	115	120	155	ALL
	--	0.00103	-0.00156	-0.00026
	--	0.00066	0.00185	0.00189
5	0	3	3	6
	--	0.08600	0.26457	0.17529
	--	0.00295	0.01235	0.09814
6	0	3	3	6
	--	0.04171	0.07907	0.06039
	--	0.00276	0.00307	0.02063
7	0	3	3	6
	--	0.00091	0.00675	0.00383
	--	0.00028	0.00367	0.00396
8	0	3	3	6
	--	-0.00870	-0.05607	-0.03239
	--	0.00781	0.00531	0.02663
	115	120	155	ALL
9	3	0	0	3
	0.00107	--	--	0.00107
	0.00109	--	--	0.00109
ALL	3	24	21	48
	0.00107	0.01917	0.09421	0.05087
	0.00109	0.03073	0.14792	0.10622

Tabulation of Weight Loss by Detergent/Cleaner (Rows) and Concentration (Normalized to -1, +1 range, Columns)

ROWS: Det COLUMNS: Conc

	-1	0	1	ALL
1	3 0.00425 0.00261	0 -- --	3 0.35823 0.00257	6 0.18124 0.19389
2	0 -- --	3 -0.00008 0.00018	0 -- --	3 -0.00008 0.00018
3	3 0.02822 0.01200	0 -- --	3 0.00850 0.00478	6 0.01836 0.01354
4	3 -0.00156 0.00185	0 -- --	3 0.00103 0.00066	6 -0.00026 0.00189
5	3 0.08600 0.00295	0 -- --	3 0.26457 0.01235	6 0.17529 0.09814
6	3 0.07907 0.00307	0 -- --	3 0.04171 0.00276	6 0.06039 0.02063
7	0 -- --	6 0.00383 0.00396	0 -- --	6 0.00383 0.00396
8	0 -- --	6 -0.03239 0.02663	0 -- --	6 -0.03239 0.02663
9	0 -- --	3 0.00107 0.00109	0 -- --	3 0.00107 0.00109
ALL	15 0.03920 0.03845	18 -0.00935 0.02228	15 0.13481 0.15311	48 0.05087 0.10622

CELL CONTENTS --
WtChg:N
MEAN
STD DEV

Tabulation of Weight Loss by Detergent/Cleaner (Rows) and Concentration (Normalized to -1, +1 range, Columns)

ROWS: Temp COLUMNS: Conc

	-1	0	1	ALL
115	0	3	0	3
	--	0.00107	--	0.00107
	--	0.00109	--	0.00109
120	9	9	6	24
	0.03949	-0.00262	0.02137	0.01917
	0.03694	0.00602	0.02235	0.03073
155	6	6	9	21
	0.03876	-0.02466	0.21043	0.09421
	0.04422	0.03465	0.15693	0.14792
ALL	15	18	15	48
	0.03920	-0.00935	0.13481	0.05087
	0.03845	0.02228	0.15311	0.10622

List of Data Values

ROW	Index	Method	Det	Temp	Conc	InitWt	FinalWt	WtChg
1	25	0	1	-1	-1	-0.47357	8.31180	0.003970
2	52	0	1	-1	-1	-0.49983	8.35605	0.001795
3	50	0	1	-1	-1	-0.43702	8.28933	0.006996
4	10	0	1	1	1	2.08889	8.37760	0.360731
5	12	0	1	1	1	2.02671	8.27775	0.355591
6	11	0	1	1	1	2.06013	8.26376	0.358354
7	29	0	2	-1	0	-0.81447	8.31719	0.000120
8	30	0	2	-1	0	-0.81868	8.40114	-0.000238
9	33	0	2	-1	0	-0.81729	8.32217	-0.000120
10	*	0	3	-1	-1	0.30947	8.40474	0.038773
11	*	0	3	-1	-1	0.03101	8.31042	0.015159
12	13	0	3	-1	-1	0.21459	8.32890	0.030727
13	34	0	3	1	1	-1.80434	8.30650	0.004936
14	37	0	3	1	1	-1.78420	8.28534	0.006638
15	60	0	3	1	1	-1.69778	8.31972	0.013941
16	46	0	4	-1	1	-0.93007	8.34370	0.001798
17	54	0	4	-1	1	-0.94422	8.33272	0.000600
18	56	0	4	-1	1	-0.94298	8.50496	0.000705
19	42	0	4	1	-1	-0.74212	8.33980	-0.003597
20	41	0	4	1	-1	-0.71221	8.31090	-0.001083
21	40	0	4	1	-1	-0.69933	8.33885	0.000000
22	51	0	5	-1	-1	1.18411	8.44336	0.083073
23	22	0	5	-1	-1	1.25305	8.28800	0.088965
24	55	0	5	-1	-1	1.21799	8.39116	0.085969
25	75	0	5	1	1	1.73810	8.29333	0.274526
26	98	0	5	1	1	1.45853	8.31788	0.250756
27	76	0	5	1	1	1.66651	8.32213	0.268439
28	53	0	6	-1	1	-0.07730	8.40395	0.043294
29	48	0	6	-1	1	-0.07714	8.33204	0.043308
30	49	0	6	-1	1	-0.13368	8.35604	0.038520
31	83	0	6	1	-1	0.63066	8.28645	0.081031
32	69	0	6	1	-1	0.56509	8.33478	0.075530
33	84	0	6	1	-1	0.62621	8.26293	0.080657
34	14	0	7	-1	0	0.09533	8.40909	0.001070
35	26	0	7	-1	0	0.08973	8.50704	0.000588
36	21	0	7	-1	0	0.09551	8.28990	0.001086
37	71	0	7	1	0	-0.51215	8.38677	0.010730
38	70	0	7	1	0	-0.59700	8.31553	0.003487
39	72	0	7	1	0	-0.56711	8.27955	0.006039
40	38	0	8	-1	0	0.21985	8.35435	-0.003711
41	45	0	8	-1	0	0.05586	8.30655	-0.017700

42	47	0	8	-1	0	0.20843	8.32609	-0.004684
43	87	0	8	1	0	-1.11970	8.42381	-0.055469
44	81	0	8	1	0	-1.06789	8.30304	-0.051092
45	80	0	8	1	0	-1.19297	8.29284	-0.061657
46	44	0	9	-1	0	0.58077	8.44186	0.002014
47	43	0	9	-1	0	0.57258	8.27924	0.001329
48	39	0	9	-1	0	0.55527	8.33269	-0.000120

Regression of Weight Loss on Detergent, Temperature, and Concentration
Linear Model

The regression equation is
WtChg = 0.132 - 0.0157 Det + 0.0322 Temp + 0.0414 Conc

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	0.13235	0.02872	4.61	0.000	
Det	-0.015689	0.005216	-3.01	0.004	1.0
Temp	0.03215	0.01297	2.48	0.017	1.0
Conc	0.04138	0.01627	2.54	0.015	1.0

s = 0.08799   R-sq = 35.8%   R-sq(adj) = 31.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	3	0.189677	0.063226	8.17	0.000
Error	44	0.340654	0.007742		
Total	47	0.530331			

SOURCE	DF	SEQ SS
Det	1	0.073550
Temp	1	0.066075
Conc	1	0.050052

Unusual Observations

Obs.	Det	WtChg	Fit	Stdev.Fit	Residual	St.Resid
4	1.00	0.3607	0.1902	0.0312	0.1705	2.07R
5	1.00	0.3556	0.1902	0.0312	0.1654	2.01R
6	1.00	0.3584	0.1902	0.0312	0.1682	2.04R

R denotes an obs. with a large st. resid.

Pure error test - F = 970.99   P = 0.0000   DF(pure error) = 32

Second-Order Model

The regression equation is
WtChg = 0.105 - 0.0124 Det + 0.0831 Temp + 0.0742 Conc - 0.0117 C11
- 0.0119 C12 + 0.0657 C13 - 0.0069 C14

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	0.10538	0.03828	2.75	0.009	
Det	-0.012400	0.006344	-1.95	0.058	1.9
Temp	0.08311	0.03828	2.17	0.036	11.7
Conc	0.07419	0.04982	1.49	0.144	12.6
C11	-0.011679	0.006344	-1.84	0.073	9.7
C12	-0.01193	0.01096	-1.09	0.283	10.6
C13	0.06571	0.04982	1.32	0.195	12.3
C14	-0.00693	0.01096	-0.63	0.531	10.6

s = 0.07690 R-sq = 55.4% R-sq(adj) = 47.6%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	7	0.293774	0.041968	7.10	0.000
Error	40	0.236557	0.005914		
Total	47	0.530331			

SOURCE	DF	SEQ SS
Det	1	0.073550
Temp	1	0.066075
Conc	1	0.050052
C11	1	0.066667
C12	1	0.003928
C13	1	0.031143
C14	1	0.002359

Unusual Observations

Obs.	Det	WtChg	Fit	Stdev.Fit	Residual	St.Resid
13	3.00	0.0049	0.1996	0.0251	-0.1946	-2.68R
14	3.00	0.0066	0.1996	0.0251	-0.1929	-2.65R
15	3.00	0.0139	0.1996	0.0251	-0.1856	-2.55R
25	5.00	0.2745	0.1137	0.0339	0.1608	2.33R
27	5.00	0.2684	0.1137	0.0339	0.1547	2.24R

R denotes an obs. with a large st. resid.

Pure error test - F = 1010.19 P = 0.0000 DF(pure error) = 32

Regression of Weight Loss on Temperature, Concentration, and Indicator Variables for Detergetn/Cleaner Using CFC-113 as Control

The regression equation is
WtChg = 0.0313 + 0.0302 Temp + 0.0418 Conc + 0.150 C21 - 0.0012 C22
- 0.0129 C23 - 0.0315 C24 + 0.144 C25 + 0.0291 C26 - 0.0274 C27
- 0.0636 C28

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	0.03125	0.03641	0.86	0.396	
Temp	0.030180	0.009530	3.17	0.003	1.2
Conc	0.04177	0.01128	3.70	0.001	1.0
C21	0.14999	0.04408	3.40	0.002	2.8
C22	-0.00115	0.04970	-0.02	0.982	1.9
C23	-0.01289	0.04408	-0.29	0.772	2.8
C24	-0.03152	0.04408	-0.71	0.479	2.8
C25	0.14403	0.04408	3.27	0.002	2.8
C26	0.02914	0.04408	0.66	0.513	2.8
C27	-0.02742	0.04408	-0.62	0.538	2.8
C28	-0.06364	0.04408	-1.44	0.157	2.8

s = 0.06087 R-sq = 74.2% R-sq(adj) = 67.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	10	0.393242	0.039324	10.61	0.000
Error	37	0.137089	0.003705		
Total	47	0.530331			

SOURCE	DF	SEQ SS
Temp	1	0.070136
Conc	1	0.049498
C21	1	0.109476
C22	1	0.000115
C23	1	0.002488
C24	1	0.012208
C25	1	0.122055
C26	1	0.018632
C27	1	0.000913
C28	1	0.007722

Pure error test - F = 933.99 P = 0.0000 DF(pure error) = 32

Appendix E

Regression Analysis of Weight Loss Versus Cleaner Concentration (Experiment No. 2)

REGRESSION ANALYSIS OF EXPERIMENT NO. 2 SOAKING DATA

The regression equation is
WtLoss = - 0.339 + 0.00311 Temp + 0.206 lnConc - 0.00263 T*LnC + 0.139 lnC2

Predictor	Coef	Stdev	t-ratio	p
Constant	-0.33910	0.04987	-6.80	0.000
Temp	0.0031135	0.0003503	8.89	0.000
lnConc	0.20611	0.03810	5.41	0.000
T*LnC	-0.0026345	0.0002229	-11.82	0.000
lnC2	0.138998	0.008294	16.76	0.000

s = 0.01251   R-sq = 99.5%   R-sq(adj) = 99.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	4	0.55658	0.13915	888.81	0.000
Error	19	0.00297	0.00016		
Total	23	0.55956			

SOURCE	DF	SEQ SS
Temp	1	0.00312
lnConc	1	0.48762
T*LnC	1	0.02188
lnC2	1	0.04397

Pure error test - F = 11.69   P = 0.0003   DF(pure error) = 16

REGRESSION ANALYSIS OF EXPERIMENT NO. 2 SONICATION DATA

The regression equation is
WtLoss = 0.0287 -0.000077 Temp - 0.0448 lnC +0.000024 TlnC + 0.0236 lnC2

Predictor	Coef	Stdev	t-ratio	p
Constant	0.02873	0.01176	2.44	0.024
Temp	-0.00007676	0.00008259	-0.93	0.364
lnC	-0.044795	0.008983	-4.99	0.000
TlnC	0.00002373	0.00005254	0.45	0.657
lnC2	0.023576	0.001955	12.06	0.000

s = 0.002950   R-sq = 97.4%   R-sq(adj) = 96.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	4	0.0062018	0.0015504	178.16	0.000
Error	19	0.0001653	0.0000087		
Total	23	0.0063671			

SOURCE	DF	SEQ SS
Temp	1	0.0000135
lnC	1	0.0049216
TlnC	1	0.0000018
lnC2	1	0.0012649

Unusual Observations

Obs.	Temp	WtLoss	Fit	Stdev.Fit	Residual	St.Resid
11	120	0.047000	0.041849	0.001456	0.005151	2.01R

R denotes an obs. with a large st. resid.

Pure error test - F = 12.15   P = 0.0002   DF(pure error) = 16

Appendix F

Regression Analysis for Determining Most Hostile Conditions (Experiment No. 3)

Equation for Soaking: Experiment No. 3

```
The regression equation is
SoakWtLs = - 0.0367 + 0.0129 C-1+1 - 0.00153 TempCen - 0.0873 TCen*CCn
           - 0.0102 CCen^2 + 0.0080 4750 + 0.0894 An2017 + 0.0189 CDA260
           + 0.130 Versa + 0.0029 PFDeg + 0.0426 EZE244 + 0.102 Bru815
           + 0.243 Intx8284 - 0.0037 X2031 - 0.0084 DeiH20
```

176 cases used

Predictor	Coef	Stdev	t-ratio	p
Constant	-0.03666	0.02552	-1.44	0.153
C-1+1	0.012904	0.009160	1.41	0.161
TempCen	-0.001531	0.006477	-0.24	0.813
TCen*CCn	-0.08729	0.02259	-3.86	0.000
CCen^2	-0.01025	0.02099	-0.49	0.626
4750	0.00801	0.01650	0.49	0.628
An2017	0.08942	0.01650	5.42	0.000
CDA260	0.01887	0.01650	1.14	0.254
Versa	0.12959	0.03345	3.87	0.000
PFDeg	0.00290	0.03084	0.09	0.925
EZE244	0.04262	0.02748	1.55	0.123
Bru815	0.10154	0.04518	2.25	0.026
Intx8284	0.24253	0.04518	5.37	0.000
X2031	-0.00373	0.02748	-0.14	0.892
DeiH20	-0.00836	0.02748	-0.30	0.761

s = 0.07232   R-sq = 47.2%   R-sq(adj) = 42.6%

Equation for Sonication: Experiment No. 3

```
The regression equation is
SoniWtLs = - 0.0028 - 0.00384 C-1+1 + 0.00544 TempCen - 0.00070 TCen*CCn
           + 0.0048 CCen^2 - 0.00062 4750 + 0.0289 An2017 + 0.00003 CDA260
           - 0.0080 Versa - 0.0002 PFDeg + 0.0462 EZE244 + 0.0026 Bru815
           - 0.0074 Intx8125 + 0.0032 Intx8284 - 0.0061 X2031 - 0.0052 DeiH20
```

175 cases used.

Predictor	Coef	Stdev	t-ratio	p
Constant	-0.00279	0.01144	-0.24	0.808
C-1+1	-0.003840	0.006153	-0.62	0.533
TempCen	0.005436	0.003911	1.39	0.166
TCen*CCn	-0.000705	0.007774	-0.09	0.928
CCen^2	0.00477	0.01576	0.30	0.762
4750	-0.000623	0.007265	-0.09	0.932
An2017	0.028856	0.007265	3.97	0.000
CDA260	0.000031	0.007265	0.00	0.997
Versa	-0.00801	0.01555	-0.52	0.607
PFDeg	-0.00021	0.01344	-0.02	0.988
EZE244	0.04616	0.01243	3.71	0.000
Bru815	0.00256	0.01999	0.13	0.898
Intx8125	-0.00740	0.01999	-0.37	0.712
Intx8284	0.00318	0.02055	0.15	0.877
X2031	-0.00609	0.01228	-0.50	0.621
DeiH20	-0.00521	0.01228	-0.42	0.672

s = 0.03151   R-sq = 33.8%   R-sq(adj) = 27.6%

Pure error test - F = 31.80 P = 0.0000 DF(pure error) = 111

Appendix G

Regression Analysis of Metals Tested in Most Hostile Conditions (Experiment No. 4)

In performing regression analysis on a set of data, one tests the null hypothesis that all coefficients of the independent variable terms are equal to zero. A statistical test called a t-test is performed on the result to determine if it is reasonable to reject the null hypothesis with a previously specified degree of confidence. The appropriate value is found in a statistical table of values of the t-statistic, using "alpha"* and the number of degrees of freedom of the data. Alpha is the probability that one will reject the null hypothesis when it is true, and its values should be selected prior to the experiment. The absolute value of t associated with each fitted coefficient is compared to the t-value from the table. If it exceeds this value, the term is said to be statistically significant at the $100(1-\alpha)$ percent level.

This appendix is a list of the calculations of the regression analysis performed on the metals tested under the most hostile conditions, namely 120 F and at the high cleaner concentrations. Table G-1 lists the t values for the metal-detergent/cleaner combinations at the 80, 95, and 99 percent significance levels.

* alpha for one-tailed test or alpha/2 for a 2-tailed test.

AA 6061 16-Hour Soak (Experiment No. 4)

```
MTB > READ 'A:AL6061SK.PRN' Detergent, Weight Loss
     27 ROWS READ

MTB > EXECUTE 'A:EXP4.MTJ'
```

ROW	Detergent	Weight Loss
1	1	0.48419
2	1	0.47802
3	1	0.47315
4	2	0.00403
5	2	0.00449
6	2	0.00375
7	3	0.13870
8	3	0.18842
9	3	0.15707
10	4	0.00402
11	4	0.00533
12	4	0.00496
13	5	0.21816
14	5	0.22208
15	5	0.22275
16	6	0.03193
17	6	0.02774
18	6	0.03487
19	7	0.00377
20	7	0.00298
21	7	0.00242
22	8	-0.00375
23	8	-0.01480
24	8	-0.00309
25	9	0.00000
26	9	-0.00107
27	9	-0.00162

```
The regression equation is
Weight Loss = - 0.00090 + 0.479 Versa + 0.00499 PF + 0.162 EZE244
              + 0.00567 Brulin + 0.222 In8125 + 0.0324 In8284
              + 0.00395 Kyzen - 0.00632 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	-0.000897	0.005188	-0.17	0.865	
Versa	0.479350	0.007337	65.34	0.000	1.8
PF	0.004987	0.007337	0.68	0.505	1.8
EZE244	0.162293	0.007337	22.12	0.000	1.8
Brulin	0.005667	0.007337	0.77	0.450	1.8
In8125	0.221893	0.007337	30.24	0.000	1.8
In8284	0.032410	0.007337	4.42	0.000	1.8
Kyzen	0.003953	0.007337	0.54	0.597	1.8
DIH2O	-0.006317	0.007337	-0.86	0.401	1.8

```
s = 0.008986     R-sq = 99.8%     R-sq(adj) = 99.7%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	0.646997	0.080875	1001.66	0.000
Error	18	0.001453	0.000081		
Total	26	0.648451			

SOURCE	DF	SEQ SS
Versa	1	0.484480
PF	1	0.007940
EZE244	1	0.036634
Brulin	1	0.005000
In8125	1	0.110303
In8284	1	0.002480
Kyzen	1	0.000101
DIH2O	1	0.000060

Unusual Observations

Obs.	Versa	C2	Fit	Stdev.Fit	Residual	St.Resid
7	0.00	0.13870	0.16140	0.00519	-0.02270	-3.09R
8	0.00	0.18842	0.16140	0.00519	0.02702	3.68R

R denotes an obs. with a large st. resid.
Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.47845	0.00553
2	3	0.00409	0.00037
3	3	0.16140	0.02514
4	3	0.00477	0.00068
5	3	0.22100	0.00248
6	3	0.03151	0.00358
7	3	0.00306	0.00068
8	3	-0.00721	0.00658
9	3	-0.00090	0.00082
ALL	27	0.09957	0.15793

AA 6061, Sonication (Experiment No. 4)

```
MTB > READ 'A:AL6061SN.PRN' Detergent, Weight Loss
     27 ROWS READ
MTB > EXECUTE 'A:EXP4.MTJ'
```

ROW	Detergent	Weight Loss
1	1	0.02519
2	1	0.02901
3	1	0.03096
4	2	0.00054
5	2	0.00214
6	2	0.00161
7	3	0.03392
8	3	0.02886
9	3	0.02274
10	4	0.00243
11	4	0.00107
12	4	0.00150
13	5	0.00386
14	5	0.00433
15	5	0.00619
16	6	0.00608
17	6	0.00599
18	6	0.00670
19	7	0.00292
20	7	0.00241
21	7	0.00243
22	8	0.00187
23	8	0.00256
24	8	0.00266
25	9	0.00257
26	9	0.00213
27	9	0.00215

```
The regression equation is
Weight Loss = 0.00228 + 0.0261 Versa - 0.00085 PF + 0.0262 EZE244
              - 0.00062 Brulin + 0.00251 In8125 + 0.00397 In8284
              + 0.00030 Kyzen + 0.00008 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	0.002283	0.001263	1.81	0.087	
Versa	0.026103	0.001787	14.61	0.000	1.8
PF	-0.000853	0.001787	-0.48	0.639	1.8
EZE244	0.026223	0.001787	14.68	0.000	1.8
Brulin	-0.000617	0.001787	-0.35	0.734	1.8
In8125	0.002510	0.001787	1.40	0.177	1.8
In8284	0.003973	0.001787	2.22	0.039	1.8
Kyzen	0.000303	0.001787	0.17	0.867	1.8
DIH2O	0.000080	0.001787	0.04	0.965	1.8

```
s = 0.002188     R-sq = 97.3%     R-sq(adj) = 96.1%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	0.00306636	0.00038330	80.04	0.000
Error	18	0.00008620	0.00000479		
Total	26	0.00315257			

SOURCE	DF	SEQ SS
Versa	1	0.00130842
PF	1	0.00007919
EZE244	1	0.00163058
Brulin	1	0.00000990
In8125	1	0.00000485
In8284	1	0.00003327
Kyzen	1	0.00000014
DIH2O	1	0.00000001

Unusual Observations

Obs.	Versa	C2	Fit	Stdev.Fit	Residual	St.Resid
7	0.00	0.033920	0.028507	0.001263	0.005413	3.03R
9	0.00	0.022740	0.028507	0.001263	-0.005767	-3.23R

R denotes an obs. with a large st. resid.
Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.028387	0.002935
2	3	0.001430	0.000815
3	3	0.028507	0.005598
4	3	0.001667	0.000695
5	3	0.004793	0.001232
6	3	0.006257	0.000387
7	3	0.002587	0.000289
8	3	0.002363	0.000430
9	3	0.002283	0.000248
ALL	27	0.008697	0.011011

Beryllium Copper (CDA172) 16-Hour Soak (Experiment No. 4)

```
MTB > READ 'A:CDA172SK.PRN' Detergent, Weight Loss
     27 ROWS READ

MTB > EXECUTE 'A:EXP4.MTJ'
```

ROW	Detergent	Weight Loss
1	1	0.01736
2	1	0.01786
3	1	0.01775
4	2	0.00120
5	2	0.00105
6	2	0.00134
7	3	0.06067
8	3	0.05469
9	3	0.06160
10	4	0.04589
11	4	0.06497
12	4	0.05509
13	5	0.02061
14	5	0.01887
15	5	0.01899
16	6	0.03269
17	6	0.03361
18	6	0.03277
19	7	0.00723
20	7	0.00699
21	7	0.00722
22	8	0.00106
23	8	0.00089
24	8	0.00102
25	9	0.00057
26	9	0.00066
27	9	0.00067

```
The regression equation is
Weight Loss = 0.00063 + 0.0170 Versa + 0.00056 PF + 0.0584 EZE244 + 0.0547 Brulin
            + 0.0189 In8125 + 0.0324 In8284 + 0.00651 Kyzen + 0.00036 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	0.000633	0.001985	0.32	0.753	
Versa	0.017023	0.002808	6.06	0.000	1.8
PF	0.000563	0.002808	0.20	0.843	1.8
EZE244	0.058353	0.002808	20.78	0.000	1.8
Brulin	0.054683	0.002808	19.48	0.000	1.8
In8125	0.018857	0.002808	6.72	0.000	1.8
In8284	0.032390	0.002808	11.54	0.000	1.8
Kyzen	0.006513	0.002808	2.32	0.032	1.8
DIH2O	0.000357	0.002808	0.13	0.900	1.8

```
s = 0.003439     R-sq = 98.3%     R-sq(adj) = 97.6%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	0.0125239	0.0015655	132.37	0.000
Error	18	0.0002129	0.0000118		
Total	26	0.0127368			

SOURCE	DF	SEQ SS
Versa	1	0.0000526
PF	1	0.0014978
EZE244	1	0.0040229
Brulin	1	0.0046354
In8125	1	0.0001962
In8284	1	0.0020385
Kyzen	1	0.0000803
DIH2O	1	0.0000002

Unusual Observations

Obs.	Versa	Weight Loss	Fit	Stdev.Fit	Residual	St.Resid
10	0.00	0.045890	0.055317	0.001985	-0.009427	-3.36R
11	0.00	0.064970	0.055317	0.001985	0.009653	3.44R

R denotes an obs. with a large st. resid.
Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.017657	0.000263
2	3	0.001197	0.000145
3	3	0.058987	0.003750
4	3	0.055317	0.009542
5	3	0.019490	0.000972
6	3	0.033023	0.000510
7	3	0.007147	0.000136
8	3	0.000990	0.000089
9	3	0.000633	0.000055
ALL	27	0.021604	0.022133

Beryllium Copper (CDA172) Sonication (Experiment No. 4)

```
MTB > READ 'A:CDA172SN.PRN' Detergent, Weight Loss
     27 ROWS READ

MTB > EXECUTE 'A:EXP4.MTJ'
```

ROW	Detergent	Weight Loss
1	1	0.00118
2	1	0.00116
3	1	0.00094
4	2	0.00066
5	2	0.00031
6	2	0.00014
7	3	0.00220
8	3	0.00248
9	3	0.00313
10	4	0.00174
11	4	0.00159
12	4	0.00193
13	5	0.00118
14	5	0.00084
15	5	0.00071
16	6	0.00197
17	6	0.00189
18	6	0.00225
19	7	-0.00116
20	7	-0.00111
21	7	-0.00107
22	8	0.00000
23	8	-0.00022
24	8	-0.00035
25	9	-0.00040
26	9	-0.00013
27	9	-0.00004

```
The regression equation is
Weight Loss = - 0.000190 + 0.00128 Versa +0.000560 PF + 0.00279 EZE244
              + 0.00194 Brulin + 0.00110 In8125 + 0.00223 In8284
              - 0.000923 Kyzen -0.000000 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	-0.0001900	0.0001371	-1.39	0.183	
Versa	0.0012833	0.0001939	6.62	0.000	1.8
PF	0.0005600	0.0001939	2.89	0.010	1.8
EZE244	0.0027933	0.0001939	14.40	0.000	1.8
Brulin	0.0019433	0.0001939	10.02	0.000	1.8
In8125	0.0011000	0.0001939	5.67	0.000	1.8
In8284	0.0022267	0.0001939	11.48	0.000	1.8
Kyzen	-0.0009233	0.0001939	-4.76	0.000	1.8
DIH2O	-0.0000000	0.0001939	-0.00	1.000	1.8

```
s = 0.0002375    R-sq = 97.2%     R-sq(adj) = 95.9%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	3.47811E-05	4.34763E-06	77.06	0.000
Error	18	1.01553E-06	5.64185E-08		
Total	26	3.57966E-05			

SOURCE	DF	SEQ SS
Versa	1	2.74491E-07
PF	1	5.55450E-07
EZE244	1	1.10065E-05
Brulin	1	5.34848E-06
In8125	1	1.43840E-06
In8284	1	1.44527E-05
Kyzen	1	1.70509E-06
DIH2O	1	2.78106E-37

Unusual Observations

Obs.	Versa	C2	Fit	Stdev.Fit	Residual	St.Resid
7	0.00	0.002200	0.002603	0.000137	-0.000403	-2.08R
9	0.00	0.003130	0.002603	0.000137	0.000527	2.72R

R denotes an obs. with a large st. resid.
Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.00109	0.00013
2	3	0.00037	0.00027
3	3	0.00260	0.00048
4	3	0.00175	0.00017
5	3	0.00091	0.00024
6	3	0.00204	0.00019
7	3	-0.00111	0.00005
8	3	-0.00019	0.00018
9	3	-0.00019	0.00019
ALL	27	0.00081	0.00117

Chromium Copper (CDA182) 16-Hour Soak (Experiment No. 4)

```
MTB > READ 'A:CDA182SK.PRN' Detergent, Weight Loss
     27 ROWS READ

MTB > EXECUTE 'A:EXP4.MTJ'
```

ROW	Detergent	Weight Loss
1	1	0.02002
2	1	0.02111
3	1	0.02044
4	2	0.00049
5	2	0.00073
6	2	0.00049
7	3	0.05509
8	3	0.05176
9	3	0.05638
10	4	0.04210
11	4	0.04282
12	4	0.04295
13	5	-0.00292
14	5	0.00073
15	5	-0.00102
16	6	0.03644
17	6	0.03609
18	6	0.03534
19	7	0.00642
20	7	0.00575
21	7	0.00649
22	8	0.00107
23	8	0.00084
24	8	0.00091
25	9	-0.00019
26	9	-0.00027
27	9	-0.00008

```
The regression equation is
Weight Loss = -0.000180 + 0.0207 Versa +0.000750 PF + 0.0546 EZE244
              + 0.0428 Brulin -0.000890 In8125 + 0.0361 In8284
              + 0.00640 Kyzen + 0.00112 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	-0.0001800	0.0006102	-0.30	0.771	
Versa	0.0207033	0.0008629	23.99	0.000	1.8
PF	0.0007500	0.0008629	0.87	0.396	1.8
EZE244	0.0545900	0.0008629	63.26	0.000	1.8
Brulin	0.0428033	0.0008629	49.60	0.000	1.8
In8125	-0.0008900	0.0008629	-1.03	0.316	1.8
In8284	0.0361367	0.0008629	41.88	0.000	1.8
Kyzen	0.0064000	0.0008629	7.42	0.000	1.8
DIH2O	0.0011200	0.0008629	1.30	0.211	1.8

```
s = 0.001057     R-sq = 99.8%     R-sq(adj) = 99.7%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	0.0110645	0.0013831	1238.29	0.000
Error	18	0.0000201	0.0000011		
Total	26	0.0110846			

SOURCE	DF	SEQ SS
Versa	1	0.0000255
PF	1	0.0009750
EZE244	1	0.0041821
Brulin	1	0.0029327
In8125	1	0.0003344
In8284	1	0.0025447
Kyzen	1	0.0000682
DIH2O	1	0.0000019

Unusual Observations

Obs.	Versa	C2	Fit	Stdev.Fit	Residual	St.Resid
8	0.00	0.051760	0.054410	0.000610	-0.002650	-3.07R
9	0.00	0.056380	0.054410	0.000610	0.001970	2.28R
13	0.00	-0.002920	-0.001070	0.000610	-0.001850	-2.14R
14	0.00	0.000730	-0.001070	0.000610	0.001800	2.09R

R denotes an obs. with a large st. resid.
Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.02052	0.00055
2	3	0.00057	0.00014
3	3	0.05441	0.00238
4	3	0.04262	0.00046
5	3	-0.00107	0.00183
6	3	0.03596	0.00056
7	3	0.00622	0.00041
8	3	0.00094	0.00012
9	3	-0.00018	0.00010
ALL	27	0.01778	0.02065

Chromium Copper (CDA182) Sonication (Experiment No. 4)

```
MTB > READ 'A:CDA182SN.PRN' Detergent, Weight Loss
     27 ROWS READ

MTB > execute 'a:exp4.mtj'
```

ROW	Detergent	Weight Loss
1	1	0.00171
2	1	0.00141
3	1	0.00164
4	2	0.00023
5	2	0.00011
6	2	0.00023
7	3	0.00383
8	3	0.00409
9	3	0.00505
10	4	0.00171
11	4	0.00262
12	4	0.00176
13	5	0.00261
14	5	0.00214
15	5	0.00137
16	6	0.00295
17	6	0.00332
18	6	0.00316
19	7	-0.00225
20	7	-0.00164
21	7	-0.00159
22	8	0.00068
23	8	0.00081
24	8	0.00053
25	9	0.00030
26	9	-0.00008
27	9	-0.00011

```
The regression equation is
Weight Loss = 0.000037 + 0.00155 Versa +0.000153 PF + 0.00429 EZE244
              + 0.00199 Brulin + 0.00200 In8125 + 0.00311 In8284
              - 0.00186 Kyzen +0.000637 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	0.0000367	0.0002226	0.16	0.871	
Versa	0.0015500	0.0003147	4.92	0.000	1.8
PF	0.0001533	0.0003147	0.49	0.632	1.8
EZE244	0.0042867	0.0003147	13.62	0.000	1.8
Brulin	0.0019933	0.0003147	6.33	0.000	1.8
In8125	0.0020033	0.0003147	6.37	0.000	1.8
In8284	0.0031067	0.0003147	9.87	0.000	1.8
Kyzen	-0.0018633	0.0003147	-5.92	0.000	1.8
DIH2O	0.0006367	0.0003147	2.02	0.058	1.8

```
s = 0.0003855    R-sq = 96.8%     R-sq(adj) = 95.3%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	0.000080012	0.000010001	67.31	0.000
Error	18	0.000002675	0.000000149		
Total	26	0.000082686			

SOURCE	DF	SEQ SS
Versa	1	0.000000181
PF	1	0.000004427
EZE244	1	0.000028126
Brulin	1	0.000003701
In8125	1	0.000005643
In8284	1	0.000027808
Kyzen	1	0.000009519
DIH2O	1	0.000000608

Unusual Observations

Obs.	Versa	C2	Fit	Stdev.Fit	Residual	St.Resid
9	0.00	0.005050	0.004323	0.000223	0.000727	2.31R
15	0.00	0.001370	0.002040	0.000223	-0.000670	-2.13R

R denotes an obs. with a large st. resid.
Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.00159	0.00016
2	3	0.00019	0.00007
3	3	0.00432	0.00064
4	3	0.00203	0.00051
5	3	0.00204	0.00063
6	3	0.00314	0.00019
7	3	-0.00183	0.00037
8	3	0.00067	0.00014
9	3	0.00004	0.00023
ALL	27	0.00136	0.00178

Chromium Steel (52100) 16-Hour Soak (Experiment No. 4)

```
MTB > READ 'A:52100SK.PRN' Detergent, Weight Loss
     27 ROWS READ

MTB > execute 'a:exp4.mtj'
```

ROW	Detergent	Weight Loss
1	1	0.00275
2	1	0.00257
3	1	0.00287
4	2	0.00184
5	2	0.00149
6	2	0.00140
7	3	0.00202
8	3	0.00145
9	3	0.00164
10	4	0.00167
11	4	0.00181
12	4	0.00138
13	5	0.10609
14	5	0.11983
15	5	0.11866
16	6	0.99176
17	6	1.04438
18	6	1.05017
19	7	0.00081
20	7	0.00078
21	7	0.00051
22	8	0.04779
23	8	0.04999
24	8	0.04254
25	9	0.00004
26	9	0.00019
27	9	0.00009

```
The regression equation is
Weight Loss = 0.00011 + 0.00262 Versa + 0.00147 PF + 0.00160 EZE244
              + 0.00151 Brulin + 0.115 In8125 + 1.03 In8284 + 0.00059 Kyzen
              + 0.0467 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	0.000107	0.006408	0.02	0.987	
Versa	0.002623	0.009062	0.29	0.776	1.8
PF	0.001470	0.009062	0.16	0.873	1.8
EZE244	0.001597	0.009062	0.18	0.862	1.8
Brulin	0.001513	0.009062	0.17	0.869	1.8
In8125	0.114753	0.009062	12.66	0.000	1.8
In8284	1.02866	0.00906	113.51	0.000	1.8
Kyzen	0.000593	0.009062	0.07	0.949	1.8
DIH2O	0.046667	0.009062	5.15	0.000	1.8

```
s = 0.01110      R-sq = 99.9%      R-sq(adj) = 99.9%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	2.74222	0.34278	2782.78	0.000
Error	18	0.00222	0.00012		
Total	26	2.74444			

SOURCE	DF	SEQ SS
Versa	1	0.05745
PF	1	0.07504
EZE244	1	0.09990
Brulin	1	0.13997
In8125	1	0.05709
In8284	1	2.30847
Kyzen	1	0.00103
DIH2O	1	0.00327

Unusual Observations

Obs.	Versa	C2	Fit	Stdev.Fit	Residual	St.Resid
16	0.00	0.99176	1.02877	0.00641	-0.03701	-4.08R
18	0.00	1.05017	1.02877	0.00641	0.02140	2.36R

R denotes an obs. with a large st. resid.
Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.00273	0.00015
2	3	0.00158	0.00023
3	3	0.00170	0.00029
4	3	0.00162	0.00022
5	3	0.11486	0.00762
6	3	1.02877	0.03218
7	3	0.00070	0.00017
8	3	0.04677	0.00383
9	3	0.00011	0.00008
ALL	27	0.13320	0.32489

Chromium Steel (52100) Sonication (Experiment No. 4)

```
MTB > READ 'A:52100SN.PRN' Detergent, Weight Loss
     27 ROWS READ

MTB > EXECUTE 'A:EXP4.MTJ'
```

ROW	Detergent	Weight Loss
1	1	0.00104
2	1	0.00039
3	1	0.00026
4	2	-0.00021
5	2	-0.00021
6	2	-0.00031
7	3	-0.00004
8	3	-0.00004
9	3	-0.00017
10	4	0.00043
11	4	0.00060
12	4	0.00017
13	5	0.00137
14	5	0.00077
15	5	0.00095
16	6	0.00979
17	6	0.00853
18	6	0.01000
19	7	0.00009
20	7	-0.00021
21	7	-0.00017
22	8	-0.00051
23	8	-0.00026
24	8	-0.00013
25	9	-0.00017
26	9	-0.00045
27	9	-0.00030

```
The regression equation is
Weight Loss = -0.000307 +0.000870 Versa +0.000063 PF +0.000223 EZE244
              +0.000707 Brulin + 0.00134 In8125 + 0.00975 In8284
              +0.000210 Kyzen +0.000007 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	-0.0003067	0.0001963	-1.56	0.136	
Versa	0.0008700	0.0002777	3.13	0.006	1.8
PF	0.0000633	0.0002777	0.23	0.822	1.8
EZE244	0.0002233	0.0002777	0.80	0.432	1.8
Brulin	0.0007067	0.0002777	2.54	0.020	1.8
In8125	0.0013367	0.0002777	4.81	0.000	1.8
In8284	0.0097467	0.0002777	35.10	0.000	1.8
Kyzen	0.0002100	0.0002777	0.76	0.459	1.8
DIH2O	0.0000067	0.0002777	0.02	0.981	1.8

```
s = 0.0003401    R-sq = 99.1%     R-sq(adj) = 98.7%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	0.000236658	0.000029582	255.79	0.000
Error	18	0.000002082	0.000000116		
Total	26	0.000238739			

SOURCE	DF	SEQ SS
Versa	1	0.000001185
PF	1	0.000007442
EZE244	1	0.000008127
Brulin	1	0.000006032
In8125	1	0.000003197
In8284	1	0.000210588
Kyzen	1	0.000000085
DIH2O	1	0.000000000

Unusual Observations

Obs.	Versa	C2	Fit	Stdev.Fit	Residual	St.Resid
17	0.00	0.008530	0.009440	0.000196	-0.000910	-3.28R
18	0.00	0.010000	0.009440	0.000196	0.000560	2.02R

R denotes an obs. with a large st. resid.
Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.00056	0.00042
2	3	-0.00024	0.00006
3	3	-0.00008	0.00008
4	3	0.00040	0.00022
5	3	0.00103	0.00031
6	3	0.00944	0.00080
7	3	-0.00010	0.00016
8	3	-0.00030	0.00019
9	3	-0.00031	0.00014
ALL	27	0.00116	0.00303

Gold-Plated Brass 16-Hour Soak (Experiment No. 4)

```
MTB > READ 'A:260GPSK.PRN' Detergent, Weight Loss
     27 ROWS READ

MTB > EXECUTE 'A:EXP4.MTJ'
```

ROW	Detergent	Weight Loss
1	1	-0.00039
2	1	-0.00060
3	1	-0.00029
4	2	-0.00026
5	2	-0.00039
6	2	-0.00030
7	3	0.00017
8	3	-0.00056
9	3	-0.00009
10	4	-0.00013
11	4	-0.00026
12	4	-0.00026
13	5	-0.00013
14	5	-0.00048
15	5	-0.00038
16	6	0.00206
17	6	0.00180
18	6	0.00133
19	7	-0.00038
20	7	-0.00017
21	7	-0.00017
22	8	-0.00013
23	8	0.00013
24	8	0.00017
25	9	-0.00030
26	9	-0.00026
27	9	-0.00004

```
The regression equation is
Weight Loss = -0.000200 -0.000227 Versa -0.000117 PF +0.000040 EZE244
              -0.000017 Brulin -0.000130 In8125 + 0.00193 In8284
              -0.000040 Kyzen +0.000257 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	-0.0002000	0.0001221	-1.64	0.119	
Versa	-0.0002267	0.0001726	-1.31	0.206	1.8
PF	-0.0001167	0.0001726	-0.68	0.508	1.8
EZE244	0.0000400	0.0001726	0.23	0.819	1.8
Brulin	-0.0000167	0.0001726	-0.10	0.924	1.8
In8125	-0.0001300	0.0001726	-0.75	0.461	1.8
In8284	0.0019300	0.0001726	11.18	0.000	1.8
Kyzen	-0.0000400	0.0001726	-0.23	0.819	1.8
DIH2O	0.0002567	0.0001726	1.49	0.154	1.8

```
s = 0.0002114     R-sq = 93.0%      R-sq(adj) = 89.9%
```

```
Analysis of Variance

SOURCE          DF        SS             MS             F          p
Regression       8 1.06689E-05 1.33361E-06         29.84      0.000
Error           18 8.04467E-07 4.46926E-08
Total           26 1.14733E-05

SOURCE          DF     SEQ SS
Versa            1 5.81778E-07
PF               1 4.37172E-07
EZE244           1 2.21257E-07
Brulin           1 4.41000E-07
In8125           1 1.06667E-06
In8284           1 7.76551E-06
Kyzen            1 5.66722E-08
DIH2O            1 9.88167E-08

Unusual Observations
Obs.    Versa       C2         Fit    Stdev.Fit  Residual     St.Resid
  8      0.00 -0.000560 -0.000160   0.000122 -0.000400       -2.32R
 18      0.00  0.001330  0.001730   0.000122 -0.000400       -2.32R

R denotes an obs. with a large st. resid.
Cannot do pure error test

MTB > table c1;
SUBC> stats c2.

 ROWS: Detergent

              ______Weight Loss______
                N       MEAN       STD DEV

   1            3    -0.00043      0.00016
   2            3    -0.00032      0.00007
   3            3    -0.00016      0.00037
   4            3    -0.00022      0.00008
   5            3    -0.00033      0.00018
   6            3     0.00173      0.00037
   7            3    -0.00024      0.00012
   8            3     0.00006      0.00016
   9            3    -0.00020      0.00014
  ALL          27    -0.00001      0.00066
```

Gold-Plated Brass Sonication (Experiment No. 4)

```
MTB > READ 'A:260GPSN.PRN' Detergent, Weight Loss
     27 ROWS READ

MTB > EXECUTE 'A:EXP4.MTJ'
```

ROW	Detergent	Weight Loss
1	1	0.00034
2	1	-0.00013
3	1	-0.00021
4	2	-0.00112
5	2	-0.00030
6	2	-0.00017
7	3	-0.00056
8	3	-0.00039
9	3	-0.00051
10	4	0.00013
11	4	0.00017
12	4	0.00030
13	5	0.00000
14	5	-0.00013
15	5	-0.00004
16	6	0.00013
17	6	0.00061
18	6	0.00043
19	7	-0.00026
20	7	-0.00013
21	7	-0.00030
22	8	-0.00030
23	8	-0.00017
24	8	-0.00021
25	9	-0.00017
26	9	-0.00035
27	9	-0.00043

```
The regression equation is
Weight Loss = -0.000317 +0.000317 Versa -0.000213 PF -0.000170 EZE244
              +0.000517 Brulin +0.000260 In8125 +0.000707 In8284
              +0.000087 Kyzen +0.000090 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	-0.0003167	0.0001309	-2.42	0.026	
Versa	0.0003167	0.0001851	1.71	0.104	1.8
PF	-0.0002133	0.0001851	-1.15	0.264	1.8
EZE244	-0.0001700	0.0001851	-0.92	0.370	1.8
Brulin	0.0005167	0.0001851	2.79	0.012	1.8
In8125	0.0002600	0.0001851	1.40	0.177	1.8
In8284	0.0007067	0.0001851	3.82	0.001	1.8
Kyzen	0.0000867	0.0001851	0.47	0.645	1.8
DIH2O	0.0000900	0.0001851	0.49	0.633	1.8

```
s = 0.0002267    R-sq = 70.7%     R-sq(adj) = 57.6%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	2.22643E-06	2.78304E-07	5.42	0.001
Error	18	9.24867E-07	5.13815E-08		
Total	26	3.15130E-06			

SOURCE	DF	SEQ SS
Versa	1	6.58005E-08
PF	1	4.76801E-07
EZE244	1	5.13029E-07
Brulin	1	2.07360E-07
In8125	1	3.68167E-09
In8284	1	9.44136E-07
Kyzen	1	3.47222E-09
DIH2O	1	1.21500E-08

Unusual Observations

Obs.	Versa	C2	Fit	Stdev.Fit	Residual	St.Resid
4	0.00	-0.001120	-0.000530	0.000131	-0.000590	-3.19R

R denotes an obs. with a large st. resid.
Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.00000	0.00030
2	3	-0.00053	0.00052
3	3	-0.00049	0.00009
4	3	0.00020	0.00009
5	3	-0.00006	0.00007
6	3	0.00039	0.00024
7	3	-0.00023	0.00009
8	3	-0.00023	0.00007
9	3	-0.00032	0.00013
ALL	27	-0.00014	0.00035

HyMu77 16-Hour Soak (Experiment No. 4)

```
MTB > READ 'A:HYMU77SK.PRN' Detergent, Weight Loss
     27 ROWS READ

MTB > EXECUTE 'A:EXP4.MTJ'
```

ROW	Detergent	Weight Loss
1	1	0.00498
2	1	0.00485
3	1	0.00522
4	2	0.00376
5	2	0.00349
6	2	0.00363
7	3	0.00398
8	3	0.00593
9	3	0.00479
10	4	0.00346
11	4	0.00440
12	4	0.00360
13	5	0.00395
14	5	0.00439
15	5	0.00452
16	6	0.19319
17	6	0.20781
18	6	0.16192
19	7	0.00394
20	7	0.00291
21	7	0.00378
22	8	0.00263
23	8	0.00271
24	8	0.00292
25	9	0.00168
26	9	0.00165
27	9	0.00167

```
The regression equation is
Weight Loss = 0.00167 + 0.00335 Versa + 0.00196 PF + 0.00323 EZE244
              + 0.00215 Brulin + 0.00262 In8125 + 0.186 In8284
              + 0.00188 Kyzen + 0.00109 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	0.001667	0.004519	0.37	0.717	
Versa	0.003350	0.006390	0.52	0.607	1.8
PF	0.001960	0.006390	0.31	0.763	1.8
EZE244	0.003233	0.006390	0.51	0.619	1.8
Brulin	0.002153	0.006390	0.34	0.740	1.8
In8125	0.002620	0.006390	0.41	0.687	1.8
In8284	0.185973	0.006390	29.10	0.000	1.8
Kyzen	0.001877	0.006390	0.29	0.772	1.8
DIH2O	0.001087	0.006390	0.17	0.867	1.8

```
s = 0.007826     R-sq = 98.8%     R-sq(adj) = 98.3%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	0.090248	0.011281	184.17	0.000
Error	18	0.001103	0.000061		
Total	26	0.091350			

SOURCE	DF	SEQ SS
Versa	1	0.001234
PF	1	0.001798
EZE244	1	0.002170
Brulin	1	0.003269
In8125	1	0.004777
In8284	1	0.076994
Kyzen	1	0.000004
DIH2O	1	0.000002

Unusual Observations

Obs.	Versa	C2	Fit	Stdev.Fit	Residual	St.Resid
17	0.00	0.20781	0.18764	0.00452	0.02017	3.16R
18	0.00	0.16192	0.18764	0.00452	-0.02572	-4.02R

R denotes an obs. with a large st. resid.
Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.005017	0.000188
2	3	0.003627	0.000135
3	3	0.004900	0.000980
4	3	0.003820	0.000507
5	3	0.004287	0.000299
6	3	0.187640	0.023443
7	3	0.003543	0.000554
8	3	0.002753	0.000150
9	3	0.001667	0.000015
ALL	27	0.024139	0.059275

HyMu77, Sonication (Experiment No. 4)

```
MTB > READ 'A:HYMU77SN.PRN' Detergent, Weight Loss
     27 ROWS READ

MTB > EXECUTE 'A:EXP4.MTJ'
```

ROW	Detergent	Weight Loss
1	1	0.00371
2	1	0.00416
3	1	0.00289
4	2	0.00200
5	2	0.00197
6	2	0.00262
7	3	0.00348
8	3	0.00360
9	3	0.00331
10	4	0.00511
11	4	0.00544
12	4	0.00483
13	5	0.00317
14	5	0.00408
15	5	0.00303
16	6	0.00686
17	6	0.00603
18	6	0.00603
19	7	0.00256
20	7	0.00320
21	7	0.00364
22	8	0.00195
23	8	0.00182
24	8	0.00152
25	9	0.00075
26	9	0.00106
27	9	0.00135

```
The regression equation is
Weight Loss = 0.00105 + 0.00253 Versa + 0.00114 PF + 0.00241 EZE244
              + 0.00407 Brulin + 0.00237 In8125 + 0.00525 In8284
              + 0.00208 Kyzen +0.000710 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	0.0010533	0.0002474	4.26	0.000	
Versa	0.0025333	0.0003498	7.24	0.000	1.8
PF	0.0011433	0.0003498	3.27	0.004	1.8
EZE244	0.0024100	0.0003498	6.89	0.000	1.8
Brulin	0.0040733	0.0003498	11.64	0.000	1.8
In8125	0.0023733	0.0003498	6.78	0.000	1.8
In8284	0.0052533	0.0003498	15.02	0.000	1.8
Kyzen	0.0020800	0.0003498	5.95	0.000	1.8
DIH2O	0.0007100	0.0003498	2.03	0.057	1.8

```
s = 0.0004284    R-sq = 95.0%     R-sq(adj) = 92.8%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	6.34245E-05	7.92806E-06	43.19	0.000
Error	18	3.30400E-06	1.83556E-07		
Total	26	6.67285E-05			

SOURCE	DF	SEQ SS
Versa	1	2.05967E-07
PF	1	4.24021E-06
EZE244	1	6.42850E-11
Brulin	1	9.90025E-06
In8125	1	3.15375E-07
In8284	1	4.20552E-05
Kyzen	1	5.95125E-06
DIH2O	1	7.56150E-07

Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.003587	0.000644
2	3	0.002197	0.000367
3	3	0.003463	0.000146
4	3	0.005127	0.000305
5	3	0.003427	0.000570
6	3	0.006307	0.000479
7	3	0.003133	0.000543
8	3	0.001763	0.000221
9	3	0.001053	0.000300
ALL	27	0.003340	0.001602

Type 304 Stainless Steel 16-Hour Soak (Experiment No. 4)

```
MTB > READ 'A:304SK.PRN' Detergent, Weight Loss
     27 ROWS READ
MTB > EXECUTE 'A:EXP4.MTJ'
```

ROW	Detergent	Weight Loss
1	1	0.00163
2	1	0.00182
3	1	0.00162
4	2	0.00126
5	2	0.00108
6	2	0.00123
7	3	0.00105
8	3	0.00143
9	3	0.00152
10	4	0.00146
11	4	0.00134
12	4	0.00142
13	5	0.00173
14	5	0.00191
15	5	0.00153
16	6	0.00179
17	6	0.00172
18	6	0.00160
19	7	0.00174
20	7	0.00114
21	7	0.00146
22	8	0.00067
23	8	0.00093
24	8	0.00023
25	9	0.00047
26	9	0.00047
27	9	0.00062

```
The regression equation is
Weight Loss = 0.000520 + 0.00117 Versa +0.000670 PF +0.000813 EZE244
              +0.000887 Brulin + 0.00120 In8125 + 0.00118 In8284
              +0.000927 Kyzen +0.000090 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	0.0005200	0.0001149	4.53	0.000	
Versa	0.0011700	0.0001624	7.20	0.000	1.8
PF	0.0006700	0.0001624	4.12	0.001	1.8
EZE244	0.0008133	0.0001624	5.01	0.000	1.8
Brulin	0.0008867	0.0001624	5.46	0.000	1.8
In8125	0.0012033	0.0001624	7.41	0.000	1.8
In8284	0.0011833	0.0001624	7.29	0.000	1.8
Kyzen	0.0009267	0.0001624	5.71	0.000	1.8
DIH2O	0.0000900	0.0001624	0.55	0.586	1.8

```
s = 0.0001989    R-sq = 87.2%     R-sq(adj) = 81.6%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	4.87181E-06	6.08976E-07	15.39	0.000
Error	18	7.12333E-07	3.95741E-08		
Total	26	5.58414E-06			

SOURCE	DF	SEQ SS
Versa	1	5.36007E-07
PF	1	9.15237E-09
EZE244	1	2.48643E-08
Brulin	1	1.06090E-07
In8125	1	1.02443E-06
In8284	1	1.60444E-06
Kyzen	1	1.55467E-06
DIH2O	1	1.21500E-08

Unusual Observations

Obs.	Versa	C2	Fit	Stdev.Fit	Residual	St.Resid
24	0.00	0.000230	0.000610	0.000115	-0.000380	-2.34R

R denotes an obs. with a large st. resid.
Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.001690	0.000113
2	3	0.001190	0.000096
3	3	0.001333	0.000249
4	3	0.001407	0.000061
5	3	0.001723	0.000190
6	3	0.001703	0.000096
7	3	0.001447	0.000300
8	3	0.000610	0.000354
9	3	0.000520	0.000087
ALL	27	0.001291	0.000463

Type 304 Stainless Steel, Sonication (Experiment No. 4)

```
MTB > READ 'A:304SN.PRN' Detergent, Weight Loss
     27 ROWS READ

MTB > EXECUTE 'A:EXP4.MTJ'
```

ROW	Detergent	Weight Loss
1	1	0.00173
2	1	0.00142
3	1	0.00171
4	2	0.00075
5	2	0.00070
6	2	0.00082
7	3	0.00165
8	3	0.00125
9	3	0.00150
10	4	0.00173
11	4	0.00168
12	4	0.00166
13	5	0.00127
14	5	0.00143
15	5	0.00193
16	6	0.00228
17	6	0.00210
18	6	0.00233
19	7	0.00139
20	7	0.00159
21	7	0.00153
22	8	0.00142
23	8	0.00162
24	8	0.00152
25	9	0.00125
26	9	0.00115
27	9	0.00117

```
The regression equation is
Weight Loss = 0.00119 +0.000430 Versa -0.000433 PF +0.000277 EZE244
              +0.000500 Brulin +0.000353 In8125 + 0.00105 In8284
              +0.000313 Kyzen +0.000330 DIH2O
```

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	0.00119000	0.00009277	12.83	0.000	
Versa	0.0004300	0.0001312	3.28	0.004	1.8
PF	-0.0004333	0.0001312	-3.30	0.004	1.8
EZE244	0.0002767	0.0001312	2.11	0.049	1.8
Brulin	0.0005000	0.0001312	3.81	0.001	1.8
In8125	0.0003533	0.0001312	2.69	0.015	1.8
In8284	0.0010467	0.0001312	7.98	0.000	1.8
Kyzen	0.0003133	0.0001312	2.39	0.028	1.8
DIH2O	0.0003300	0.0001312	2.52	0.022	1.8

```
s = 0.0001607    R-sq = 88.9%     R-sq(adj) = 84.0%
```

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	3.73543E-06	4.66929E-07	18.09	0.000
Error	18	4.64733E-07	2.58185E-08		
Total	26	4.20016E-06			

SOURCE	DF	SEQ SS
Versa	1	4.62296E-08
PF	1	1.83544E-06
EZE244	1	5.57341E-08
Brulin	1	2.08544E-08
In8125	1	1.14817E-08
In8284	1	1.55834E-06
Kyzen	1	4.40056E-08
DIH2O	1	1.63350E-07

Unusual Observations

Obs.	Versa	C2	Fit	Stdev.Fit	Residual	St.Resid
13	0.00	0.001270	0.001543	0.000093	-0.000273	-2.08R
15	0.00	0.001930	0.001543	0.000093	0.000387	2.95R

R denotes an obs. with a large st. resid.
Cannot do pure error test

```
MTB > table c1;
SUBC> stats c2.
```

ROWS: Detergent

	Weight Loss		
	N	MEAN	STD DEV
1	3	0.001620	0.000173
2	3	0.000757	0.000060
3	3	0.001467	0.000202
4	3	0.001690	0.000036
5	3	0.001543	0.000344
6	3	0.002237	0.000121
7	3	0.001503	0.000103
8	3	0.001520	0.000100
9	3	0.001190	0.000053
ALL	27	0.001503	0.000402

Table G-1. t values for Metal-Detergent/Cleaner Combinations

Detergents/ Cleaners	Metals													
	AA6061		Beryllium Copper		Chromium Copper		Chromium Steel		Gold-Plated Brass		HyMu77		Type 304 Stainless Steel	
	16-hr Soak	Soni-cation	16-hr Soak	Soni-cation	16-hr Soak	Soni-cation	16-hr Soak	Soni-cation	16-hr Soak	Soni-cation	16-hr Soak	Soni-cation	16-hr Soak	Soni-cation
DI H_20						(2.02)	5.15					(2.03)		(2.52)
Versa Clean	65.34	14.61	6.06	6.62	23.99	4.92		(3.13)				7.24	7.20	(3.28)
Brulin 815 GD			19.48	10.02	49.6	6.33		(2.54)		(2.79)		11.64	5.46	(3.81)
Intex 8125	30.24		6.72	5.67		6.37	12.66	4.81				6.78	7.41	(2.69)
EZE 244	22.12	14.68	20.78	14.40	63.26	13.62						6.89	5.01	(2.11)
Intex 8284	4.42	(2.22)	11.54	11.48	41.88	9.87	113.51	35.10	11.18	(3.82)	29.10	15.02	7.29	7.98
Kyzen X2031			(2.32)	-4.76	7.42	-5.92						5.95	5.71	(2.39)
PF Degreaser				(2.89)								(3.27)	(4.12)	(-3.30)

Note: Empty cell = not statistically significant.

$t \geq |1.89|$ is significant at the 80 percent level (shown in parentheses).

$t \geq |4.30|$ indicates statistical significance at the 95 percent level.

$t \geq |9.93|$ is significant at the 99 percent level.

negative number = a weight gain.

Appendix H

Tables of Weight Loss Data for all the Tested Metals

The weight loss data for all the metals tested in all the experiments are listed in this appendix. The tables for the 16-hour soak and five-minute sonication testes are presented alphabetically by alloy name for experiments one through four. The tables for the one-hour and 10-minute soak tests are listed at the end of the appendix. Each table shows the alloy name, coupon number, cleaner name, test temperature, cleaner concentration type and value, and percent weight change. A positive weight change represents a weight loss and a negative weight change represents a weight gain. If the cleaner concentration was 100 volume percent, its concentration type is listed as as-prepared (as-prep), in the case if deionized water, or as-received (as-rec) for EZE 244, Kyzen X2031, PF Degreaser, and CFC-113.

Aluminum AA 2017, 16-Hour Soak Test Data
(Experiment No. 1)

Coupon ID Alloy	No.	Test	Cleaner	Temp. (F)	Conc. Type	Conc. (vol. %)	Weight Change (%)
AA 2017	25	Soak-1	Versa Clean	120	low	1.6	0.0040
AA 2017	50	Soak-1	Versa Clean	120	low	1.6	0.0070
AA 2017	52	Soak-1	Versa Clean	120	low	1.6	0.0018
AA 2017	10	Soak-1	Versa Clean	155	high	9.1	0.3607
AA 2017	11	Soak-1	Versa Clean	155	high	9.1	0.3584
AA 2017	12	Soak-1	Versa Clean	155	high	9.1	0.3556
AA 2017	29	Soak-1	PF Degreaser	120	as-rec	100	0.0001
AA 2017	30	Soak-1	PF Degreaser	120	as-rec	100	-0.0002
AA 2017	33	Soak-1	PF Degreaser	120	as-rec	100	-0.0001
AA 2017	08	Soak-1	EZE 240	120	low	2	0.0388
AA 2017	09	Soak-1	EZE 240	120	low	2	0.0152
AA 2017	13	Soak-1	EZE 240	120	low	2	0.0307
AA 2017	34	Soak-1	EZE 240	155	high	10	0.0049
AA 2017	37	Soak-1	EZE 240	155	high	10	0.0066
AA 2017	60	Soak-1	EZE 240	155	high	10	0.0139
AA 2017	46	Soak-1	Brulin 815	120	high	9.1	0.0018
AA 2017	54	Soak-1	Brulin 815	120	high	9.1	0.0006
AA 2017	56	Soak-1	Brulin 815	120	high	9.1	0.0007
AA 2017	40	Soak-1	Brulin 815	155	low	4.8	0.0000
AA 2017	41	Soak-1	Brulin 815	155	low	4.8	-0.0011
AA 2017	42	Soak-1	Brulin 815	155	low	4.8	-0.0036
AA 2017	22	Soak-1	Intex 8125	120	low	10	0.0890
AA 2017	51	Soak-1	Intex 8125	120	low	10	0.0831
AA 2017	55	Soak-1	Intex 8125	120	low	10	0.0860
AA 2017	75	Soak-1	Intex 8125	155	high	20	0.2745
AA 2017	76	Soak-1	Intex 8125	155	high	20	0.2684
AA 2017	98	Soak-1	Intex 8125	155	high	20	0.2508
AA 2017	48	Soak-1	Intex 8284	120	high	15	0.0433
AA 2017	49	Soak-1	Intex 8284	120	high	15	0.0385
AA 2017	53	Soak-1	Intex 8284	120	high	15	0.0433
AA 2017	69	Soak-1	Intex 8284	155	low	5	0.0755
AA 2017	83	Soak-1	Intex 8284	155	low	5	0.0810
AA 2017	84	Soak-1	Intex 8284	155	low	5	0.0807
AA 2017	14	Soak-1	Kyzen	120	as-rec	100	0.0011
AA 2017	21	Soak-1	Kyzen	120	as-rec	100	0.0011
AA 2017	26	Soak-1	Kyzen	120	as-rec	100	0.0006
AA 2017	70	Soak-1	Kyzen	155	as-rec	100	0.0035
AA 2017	71	Soak-1	Kyzen	155	as-rec	100	0.0107
AA 2017	72	Soak-1	Kyzen	155	as-rec	100	0.0060
AA 2017	38	Soak-1	DI H2O	120	as-pre	100	-0.0037
AA 2017	45	Soak-1	DI H2O	120	as-pre	100	-0.0177
AA 2017	47	Soak-1	DI H2O	120	as-pre	100	-0.0047
AA 2017	80	Soak-1	DI H2O	155	as-pre	100	-0.0617
AA 2017	81	Soak-1	DI H2O	155	as-pre	100	-0.0511
AA 2017	87	Soak-1	DI H2O	155	as-pre	100	-0.0555
AA 2017	39	Soak-1	CFC 113	115	as-rec	100	-0.0001
AA 2017	43	Soak-1	CFC 113	115	as-rec	100	0.0013
AA 2017	44	Soak-1	CFC 113	115	as-rec	100	0.0020

Aluminum AA 2017, Sonication Test Data
(Experiment No. 1)

Coupon ID Alloy	No.	Test	Cleaner	Temp. (F)	Conc. Type	Conc. (vol. %)	Weight Change (%)
AA 2017	17	Sonc-1	Versa Clean	120	High	9.1	0.0672
AA 2017	18	Sonc-1	Versa Clean	120	High	9.1	0.0729
AA 2017	19	Sonc-1	Versa Clean	120	High	9.1	0.0688
AA 2017	15	Sonc-1	Versa Clean	155	High	9.1	0.0619
AA 2017	16	Sonc-1	Versa Clean	155	High	9.1	0.0740
AA 2017	20	Sonc-1	Versa Clean	155	High	9.1	0.0777
AA 2017	32	Sonc-1	PF Degreaser	120	as-rec	100	-0.0001
AA 2017	35	Sonc-1	PF Degreaser	120	as-rec	100	-0.0004
AA 2017	36	Sonc-1	PF Degreaser	120	as-rec	100	-0.0015
AA 2017	64	Sonc-1	EZE 240	120	High	10	-0.0002
AA 2017	67	Sonc-1	EZE 240	120	High	10	-0.0004
AA 2017	68	Sonc-1	EZE 240	120	High	10	0.0007
AA 2017	82	Sonc-1	EZE 240	155	High	10	0.0021
AA 2017	85	Sonc-1	EZE 240	155	High	10	0.0045
AA 2017	89	Sonc-1	EZE 240	155	High	10	0.0036
AA 2017	61	Sonc-1	Brulin 815	120	low	4.8	0.0018
AA 2017	62	Sonc-1	Brulin 815	120	low	4.8	0.0046
AA 2017	63	Sonc-1	Brulin 815	120	low	4.8	0.0013
AA 2017	88	Sonc-1	Brulin 815	155	low	4.8	0.0006
AA 2017	91	Sonc-1	Brulin 815	155	low	4.8	0.0004
AA 2017	92	Sonc-1	Brulin 815	155	low	4.8	0.0008
AA 2017	73	Sonc-1	Intex 8125	120	High	10	0.0002
AA 2017	74	Sonc-1	Intex 8125	120	High	10	0.0036
AA 2017	79	Sonc-1	Intex 8125	120	High	10	0.0017
AA 2017	90	Sonc-1	Intex 8125	155	high	10	0.0087
AA 2017	101	Sonc-1	Intex 8125	155	high	10	0.0090
AA 2017	103	Sonc-1	Intex 8125	155	high	10	0.0068
AA 2017	95	Sonc-1	Intex 8284	120	low	5	0.0036
AA 2017	96	Sonc-1	Intex 8284	120	low	5	0.0042
AA 2017	97	Sonc-1	Intex 8284	120	low	5	0.0030
AA 2017	27	Sonc-1	Intex 8284	155	low	5	0.0022
AA 2017	31	Sonc-1	Intex 8284	155	low	5	0.0008
AA 2017	77	Sonc-1	Intex 8284	155	low	5	0.0020
AA 2017	65	Sonc-1	Kyzen	120	as-rec	100	0.0000
AA 2017	66	Sonc-1	Kyzen	120	as-rec	100	0.0012
AA 2017	86	Sonc-1	Kyzen	120	as-rec	100	0.0005
AA 2017	93	Sonc-1	Kyzen	155	as-rec	100	0.0000
AA 2017	99	Sonc-1	Kyzen	155	as-rec	100	0.0002
AA 2017	102	Sonc-1	Kyzen	155	as-rec	100	-0.0017
AA 2017	57	Sonc-1	DI H2O	120	as-pre	100	-0.0004
AA 2017	58	Sonc-1	DI H2O	120	as-pre	100	-0.0014
AA 2017	59	Sonc-1	DI H2O	120	as-pre	100	0.0007
AA 2017	23	Sonc-1	DI H2O	155	as-pre	100	-0.0013
AA 2017	24	Sonc-1	DI H2O	155	as-pre	100	-0.0010
AA 2017	28	Sonc-1	DI H2O	155	as-pre	100	-0.0006
AA 2017	78	Sonc-1	CFC 113	115	as-rec	100	0.0029
AA 2017	94	Sonc-1	CFC 113	115	as-rec	100	0.0033
AA 2017	100	Sonc-1	CFC 113	115	as-rec	100	0.0024

Aluminum AA 2017, 16-Hour Soak Test Data
(Experiment No. 2)

Coupon ID Alloy	No.	Test	Cleaner	Temp. (F)	Conc. Type	Conc. (vol. %)	Weight Change (%)
AA 2017-	104	soak-2	Versa Clean	120	low	1.6	0.0049
AA 2017-	105	soak-2	Versa Clean	120	low	1.6	0.0081
AA 2017-	106	soak-2	Versa Clean	120	low	1.6	0.0063
AA 2017-	107	soak-2	Versa Clean	120	nom	3.2	0.1127
AA 2017-	108	soak-2	Versa Clean	120	nom	3.2	0.1113
AA 2017-	109	soak-2	Versa Clean	120	nom	3.2	0.1146
AA 2017-	110	soak-2	Versa Clean	120	nom-2	6.3	0.2804
AA 2017-	111	soak-2	Versa Clean	120	nom-2	6.3	0.2864
AA 2017-	112	soak-2	Versa Clean	120	nom-2	6.3	0.3115
AA 2017-	113	soak-2	Versa Clean	120	high	9.1	0.4722
AA 2017-	114	soak-2	Versa Clean	120	high	9.1	0.4736
AA 2017-	115	soak-2	Versa Clean	120	high	9.1	0.4668
AA 2017-	116	soak-2	Versa Clean	155	low	1.6	0.0870
AA 2017-	117	soak-2	Versa Clean	155	low	1.6	0.0781
AA 2017-	118	soak-2	Versa Clean	155	low	1.6	0.0875
AA 2017-	119	soak-2	Versa Clean	155	nom	3.2	0.0846
AA 2017-	120	soak-2	Versa Clean	155	nom	3.2	0.0841
AA 2017-	121	soak-2	Versa Clean	155	nom	3.2	0.0841
AA 2017-	122	soak-2	Versa Clean	155	nom-2	6.3	0.2479
AA 2017-	123	soak-2	Versa Clean	155	nom-2	6.3	0.2518
AA 2017-	124	soak-2	Versa Clean	155	nom-2	6.3	0.2439
AA 2017-	125	soak-2	Versa Clean	155	high	9.1	0.3718
AA 2017-	126	soak-2	Versa Clean	155	high	9.1	0.3883
AA 2017-	127	soak-2	Versa Clean	155	high	9.1	0.3662

Aluminum AA 2017, Sonication Test Data
(Experiment No. 2)

Coupon ID Alloy	No.	Test	Cleaner	Temp. (F)	Conc. Type	Conc. (vol. %)	Weight Change (%)
AA 2017-	128	sonc-2	Versa Clean	120	low	1.6	0.0031
AA 2017-	129	sonc-2	Versa Clean	120	low	1.6	0.0054
AA 2017-	130	sonc-2	Versa Clean	120	low	1.6	0.0042
AA 2017-	134	sonc-2	Versa Clean	120	nom	3.2	0.0037
AA 2017-	135	sonc-2	Versa Clean	120	nom	3.2	0.0044
AA 2017-	136	sonc-2	Versa Clean	120	nom	3.2	0.0050
AA 2017-	140	sonc-2	Versa Clean	120	nom-2	6.3	0.0211
AA 2017-	141	sonc-2	Versa Clean	120	nom-2	6.3	0.0191
AA 2017-	142	sonc-2	Versa Clean	120	nom-2	6.3	0.0168
AA 2017-	146	sonc-2	Versa Clean	120	high	9.1	0.0420
AA 2017-	147	sonc-2	Versa Clean	120	high	9.1	0.0470
AA 2017-	148	sonc-2	Versa Clean	120	high	9.1	0.0421
AA 2017-	131	sonc-2	Versa Clean	155	low	1.6	0.0014
AA 2017-	132	sonc-2	Versa Clean	155	low	1.6	-0.0004
AA 2017-	133	sonc-2	Versa Clean	155	low	1.6	0.0026
AA 2017-	137	sonc-2	Versa Clean	155	nom	3.2	0.0042
AA 2017-	138	sonc-2	Versa Clean	155	nom	3.2	0.0032
AA 2017-	139	sonc-2	Versa Clean	155	nom	3.2	0.0044
AA 2017-	143	sonc-2	Versa Clean	155	nom-2	6.3	0.0185
AA 2017-	144	sonc-2	Versa Clean	155	nom-2	6.3	0.0178
AA 2017-	145	sonc-2	Versa Clean	155	nom-2	6.3	0.0170
AA 2017-	149	sonc-2	Versa Clean	155	high	9.1	0.0435
AA 2017-	150	sonc-2	Versa Clean	155	high	9.1	0.0393
AA 2017-	151	sonc-2	Versa Clean	155	high	9.1	0.0444